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THE

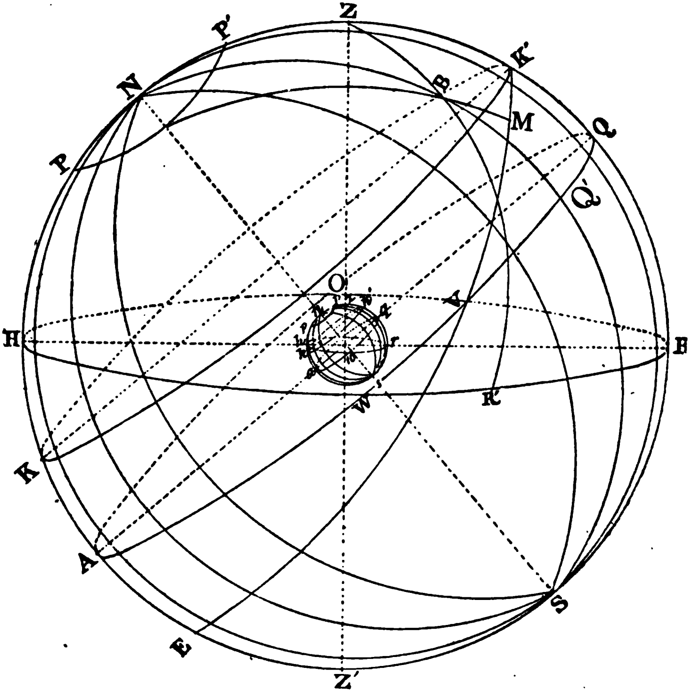
CONNECTION OF GEOGRAPHY & ASTRONOMY.

DR. A. H. DICK.

THE CONNECTION OF

GEOGRAPHY AND ASTRONOMY.

Frontispiece.



Position of a heavenly body, and Correspondence of the celestial and terrestrial spheres.

Outer circle, the celestial; *inner circle*, the terrestrial sphere. N,S, north and south poles of celestial sphere. NS, axis of the heavens. *ns* axis of the earth. *n*,*s*, north and and south poles of terrestrial sphere. AWQ, equinoctial. *awq*, equator. KK′ the northern celestial tropic. *kk′* the northern terrestrial tropic. PP′ and *pp′* the corresponding polar circles. *z* the observer's position. Z his zenith. Z′ his nadir. ZZ′ the axis of the horizon HWR′R. W, O the east and west points; H,R the north and south points, of the horizon. The outer and inner circles, and the three curves on each side through N,S, and *n*,*s*, represent corresponding meridians in the celestial and terrestrial spheres. EK′, the ecliptic. V the point Aries. B, a star, whose position may be described by BM its latitude, and VM its longitude; or by BR′ its altitude, and RR′, or HR′ its azimuth; or by BQ′, its declination, and VQ′ its right ascension.

THE CONNECTION OF
GEOGRAPHY AND ASTRONOMY

AN

ELEMENTARY TEXT BOOK

FOR

DEPARTMENT OF SCIENCE AND ART, TEACHERS'
CERTIFICATE, AND SPECIFIC SUBJECT
EXAMINATIONS.

BY

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PREFACE.

The object of the present work is to furnish a convenient, short, and sufficiently elementary text book for students of Geography preparing for the examinations on that subject prescribed by the Department of Science and Art, or by the General Committee of Council on Education. In the tables of specific subjects of the new Code, both for England and Scotland, scholars of the third year, who have chosen Physical Geography as their subject, are required to know something of "the form and size of the earth, and its motions—day and night—the seasons of the year, how they depend upon the relative positions of the earth and sun; the moon's dimensions and distance—her phases, and the general arrangement of the planetary system." In the advanced stage of the Physical Geography, of the Science Directory, students are expected to have acquired "so much elementary astronomy as relates to the position of the earth in the solar system, its magnitude and rotation, and the influence of the sun, moon and other bodies distributed through space on terrestrial phenomena." In the Government examinations for certificates as teachers, a familiar knowledge of the shape, size, and movements of the earth—and indeed, of all such geographical phenomena as depend upon Astronomy for explanation, is required. There are many excellent treatises on Astronomy from which the student might cull the truths and the explanations required; but the very seeking for them in such books implies a knowledge of the things sought; and, even when found, it is difficult to make note of them, because the explanations often depend upon previous explanations of purely astronomical facts.

The author has, therefore, selected the chief doctrines of Astronomy which bear upon Geography, and tried to explain them in simple language, assuming no previous mathematical study, and using such illustrations, and modes of explanation, as a somewhat lengthened experience in teaching the subject has led him to see are most easily understood and remembered. He has thus sought to produce a work which, while meeting the immediate wants of students of Geography, might also be a fitting introduction to more complete treatises on Mathematical Geography, and to the study of Astronomy as a science.

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THE GEOGRAPHY OF ASTRONOMY.

I.

SHAPE OF THE EARTH.

THE earth, as we call the world on which we live, is not a large plain, such that if we went far enough in any direction we should come to the edge of it; on the contrary it is round like a ball or globe, and has no edge. We know this :—

Proofs. (1.) Because when a ship sails away from us, we lose sight of the hull first, and of the top-mast last; for the surface of the sea rises up between us and the ship. The sharp line of the sea behind which the ship appears to sink is called the offing.

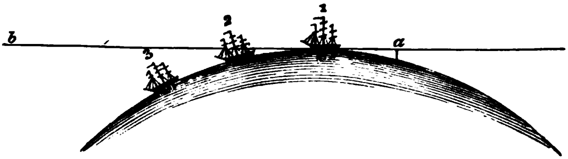

Fig. 1.—Roundness of the earth.
a, *b*, terrestrial horizon.
a, position of observer.
1, vessel wholly; 2, vessel partly in sight.
3, vessel out of sight.

(2.) Because, if it were flat, the sun, moon, and stars would each rise and set to the whole of the world at the same time. But they rise and set earlier to some places than to others. A place to the east has sunrise and sunset earlier than a place to the west. So, too, the farther we are to the east, the earlier do we see the sun, moon, and stars rise and set.

(3.) Because the shadow of the earth when it falls upon the moon, and eclipses or hides it, is *always* round. Only an object which is round like a ball or globe can have a shadow that is always round. The shadow of a ruler, or of a sixpence, or of a hat, is only round in certain positions of the light.

(4.) Because at sea or on a plain, the horizon, or line where the sky and the land or water seem to meet, is always a circle; and the higher we are above the sea or the plain, viewing it from a mast or from a mountain, the greater is the circle. This could not be if the earth had any other shape than that of a globe or ball.

(5.) Because the earth has been sailed round.

(6.) Because the level ground, or a level surface of water, rises up, as it were, 8 inches in a mile, as can be plainly seen by those who use the instrument called a spirit level. In two miles the so-called level ground, or water, rises not merely 2 × 8, or 16 miles, but 4 × 8, or 32; in three miles it rises 9 times 8, or 72 inches; and therefore two very tall men if they were six miles apart on a plain would only see each others' heads even with the best telescope, for the ground midway between their positions would rise between them to the height of 6 feet. This could only happen on a globe as large as the earth is known to be.

Definitions. The round world is suspended as it were in space like a balloon in the air; and, as we shall have proof by and by, spins round like a top once every 24 hours. The central line on which it spins is called the AXIS, and its surface round the extremities of this line is somewhat flattened, so that it is not perfectly round or spherical. The extremities of the earth's axis are called POLES; one the North, and the other the South Pole. Any division of a globe has a circle for its outline; and the circular outline of a division which cuts the globe into two equal parts is called a GREAT CIRCLE, because no greater can be drawn on the globe; while the outline of any section which does not divide the globe equally is a SMALL CIRCLE. The great circle drawn round the earth's surface at an equal distance from the North and South Poles is called the EQUATOR, and the two halves into which it divides the surface of the earth are called the Northern and the Southern Hemispheres. The Northern is that hemisphere in the middle of which the North Pole is situated; the Southern, that which has the South Pole in its centre. All places on the earth lie either on the equator, or to the north, or to the south of it. Great circles which pass round the earth through both poles, therefore from north to south, or *vice versâ*, are called MERIDIANS. Such circles, as they cross each other at the poles, have the earth's axis for their DIAMETER; and its middle point for their common centre.

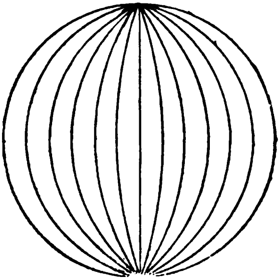

Fig. 2.—Meridian.

Celestial and terrestrial spheres. We speak of the space which surrounds the globe, with the sun, moon, and stars in it, as the CELESTIAL SPHERE. Owing to our being unable to see with the naked eye that the stars, moon, sun, and other objects in this space are really at different distances from us, one far behind the other, we imagine them all as shining like golden nails on the inner surface of a hollow sphere which surrounds the earth. We imagine, too, that this sphere, with the bright objects in it, revolves round the earth, because we are unconscious that we ourselves are being carried round within it as the earth revolves on its axis. The centre of the earth, therefore, and the centre of this imaginary celestial sphere, are the same; and the poles of the heavens are fixed points in the celestial sphere, exactly above the poles of the earth. In the celestial sphere there is, too, a circle exactly above the Equator of the Earth, which is called the EQUINOCTIAL, and may be defined as a great circle in the celestial sphere, equally distant at all points from the north and south poles of the heavens. Any place on the Equator, such as Quito, sweeps round as the earth revolves, every 24 hours, under the stars which are on the Equinoctial. Large circles passing round the heavens and crossing at the poles are celestial meridians; and as the earth revolves each terrestrial meridian sweeps round under those of the celestial sphere.

Horizon. The circle on land or sea which bounds the view on all sides where the earth and sky seem to meet, and which, as we have already learned, becomes wider the higher we are, is called the TERRESTRIAL HORIZON. To a man of ordinary height on a level plain, the most distant part of the terrestrial horizon is about five miles off; and all that such a man can see on the surface of the earth is included within the circle surrounding him at that distance. But in the heavens above and around us we always see one-half of the celestial sphere, whose lower boundary, where it seems to touch the earth and coincide with the terrestrial horizon, is a circle extended through the centre of the earth, and parallel to its level surface, as shewn by a spirit level at the point where the observer stands. It is true, as we shall find, that the point where the observer stands and the centre of the earth are about 4000 miles from each other; but at the distance of the places of the stars in the heavens, a line 4000 miles long becomes as nothing; and, therefore, the circle extended from our position to the heavens and that from the centre of the earth to the heavens appear one and the same, as the iron rails of a railroad, distant from each other by breadth of the way, seem to meet when seen at a distance along the length of the line.

Definitions.

We call the circle of the celestial sphere in which these two circles coincide, the CELESTIAL or RATIONAL HORIZON. It always divides the visible part of the heavens above from the invisible part below us. The central point of the visible half—the point, namely, above our heads—is called the ZENITH; the central point of the invisible half is called the NADIR. To an observer at the poles, the Equinoctial would be the rational horizon; the north pole of the heavens would be his *zenith*; and the south pole of the heavens, his nadir. If the observer were at any point on the equator, the north and south poles would be on his horizon, the circle of which would be formed by a meridian. At any other part of the earth the celestial horizon is inclined to the Equinoctial, and divides the celestial sphere into two halves; but in the visible half the pole, or the star near it called the POLAR STAR, will not be overhead, nor will the south pole form the nadir.

Points of the Compass. At any place, the direction towards the north pole is called the NORTH, and that towards the south pole the SOUTH. If we stand with our faces to the north the point of the horizon to the left of us is called the WEST; that to the right of us the EAST. The celestial meridian of any place is the meridian which passes through the zenith of the place and through the two poles. In doing so it cuts the horizon of the place in two points, one the north, the other the south point of the horizon; and any line or bar of steel lying on the earth in the direction of the meridian, will stretch northward and southward.

Division of Circles. Every circle, large or small, can be divided into 360 equal parts, and each of these parts, whether the circle be as small or smaller than a threepenny piece, or as large as the line round the world, is called a degree, and marked 1°. Of course the larger the circle, the larger the degrees will be. Every degree (1°) is divided into, or contains 60 minutes (60′), and every minute contains 60 seconds (60″). These minutes and seconds, be it remembered, are measures of parts of a circle, of arches or arcs—not measures of time. They are used also for measures of the angles or openings formed at the centre of the circle between any two straight lines, or radii, stretching from the central point to the ends of any arc or part of a circle. Thus, for example, 2° means either the arc of the circle, $\frac{2}{360}$ths of the whole, or it means the opening (angle) of the lines which come from the centre, one to each end of the arc of 2°. So 90° means either the quarter of a circle ($\frac{360^\circ}{4}$), or the opening at the centre between two lines, one to each end of it. 90° is called a right angle; and lines at right angles are said to be perpendicular to each other. Perpendicular in this sense should not be confounded with upright. A pencil put end on to any part of a small globe is perpendicular to the surface of that globe, though it may not be upright.

Angles of a Triangle. In any triangle, the angles—or corners formed by the sides at their meeting—are measured by the degrees of a circle they contain, and geometers can easily prove that all the three angles together are equal to 180°. Knowing, therefore, one angle of a triangle, we can easily find the sum of the other two; or knowing the sum of two, we can easily find the third—for we can subtract the number known from 180°.

Mariner's Compass. The circle of the horizon being divided into 360°, there must be 180° in the arc from the north to the south point of it, that being half round the circle; and 90° from the north to the east or west points of it, as well as from the south to the east or west points, these distances being each one-fourth of the circle, North, south, east, west, are called the cardinal points of the horizon, or compass. If we halve the 90° between the north and the west, we find the north-west point, which is therefore 45° to the west of north. If again we halve the 45° between north and northwest, we find a point 22½° west of north, which is called north-north-west. So by continuously halving or bisecting arcs, we find all the 32 points of the compass or horizon—each of which is 11¼° distant from the next. A mariner's compass consists of a magnetic needle, which has the property, when nicely balanced on a pivot, of lying always in, or very nearly in the direction of the meridian, that is between north and south, and enables the mariner to find easily any other points, by means of a circular card on which the 32 points are marked, and to which the needle is attached.

Altitude and Azimuth.

The sun rises always in the eastern and sets in the western parts of the horizon, and as seen from all countries in Europe crosses the meridian of any place in the southern part of the sky. The position of the sun, moon, or of any object in the celestial sphere, may always be told by giving its height above the horizon, that is its ALTITUDE; and its distance to the east or west round the horizon from the north or the south point of it, that is its AZIMUTH. The greatest altitude or height that any star can have is 90°, for at that height it is in the zenith; and the greatest azimuth possible is 180°, or half round the horizon from the north or the south point.

Latitude.

It is of importance that we should be able to describe exactly the position of any place on the earth's surface. For this purpose we must give at least two measurements—namely, the latitude and the longitude. The LATITUDE is the distance of a place from the equator. As we have seen, a place must be either on the equator or at some distance from it, to the north or to the south. If it be on it, the place has no latitude, because it is no distance from the equator; if it be to the south or to the north, then it has what is called north latitude or south latitude. And in the same manner as we reckon by degrees round the horizon, we may reckon by degrees round any meridian along which we travel in increasing our distance northward or southward from the equator. Latitude, then, is distance from the equator, measured along a meridian.

Greatest possible Latitude.

It is clear, that if we travel from the equator to either pole we shall have gone round one fourth of the circumference of the earth, or 90° along a meridian; and we cannot then go farther from the equator, since in moving farther on the curved earth, we should begin to approach the equator on the opposite side from our starting point. Hence the greatest possible latitude, whether north or south, which any place can have, is 90°.

Parallels of Latitude.

We shall find, by and by, that every degree on a meridian, or on a large circle round the earth, is somewhat above 69 miles in length; and thus when we say that our latitude is 30° north, or 30° south, we mean that the place in which we are lies 30 times 69 miles, and somewhat more, northward or southward from the nearest point of the equator. If we join all places on the earth that have the same latitude, the lines joining them would form circles round the earth, parallel to, or equally distant at all points from, the equator. Such circles are called PARALLELS of latitude, and it is clear that the farther they are from the equator, or the nearer to either pole, the smaller these circles are

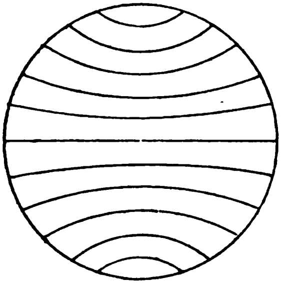

Fig. 3.—Parallels.

Longitude When we know the latitude only, we do not know exactly where a place is. A place which we know to be in 30° north latitude, may for aught we can tell be anywhere round the whole circle of the 30th parallel. We must have some means of marking at what point on that parallel it lies, before we can describe its position. The longitude is such means. LONGITUDE is the distance of any place east or west of a given meridian, measured along the parallel of latitude passing through the place. The given meridian is called the first meridian, and geographers in Great Britain take for their first meridian that which passes through Greenwich and the poles.

As latitude is reckoned from the equator, so longitude is reckoned from the first meridian; and clearly enough every place must be either on this meridian or to the east or the west of it. If on the first meridian, the place has no longitude; if to the east, it has east longitude; if to the west, west longitude.

Length of Degrees. Since the degrees of longitude are measured along the equator or the parallels of latitude, and these become smaller the nearer they are to the poles, it is clear that the degrees of longitude become shorter too, the farther north or south the circle along which they are measured. Degrees of latitude being measured on meridians, are everywhere about 69½ miles; degrees of longitude measured on the equator, which is a great circle, are of about the same length; but degrees of longitude measured on the parallel which passes east and west through Greenwich are only about 43 miles in length; those measured on the 6cth parallel are 34½ miles in length, or only half the length of those on the equator; those measured on the 70th parallel are 23½ miles long, while those on the 80th are about 12. Thus the degrees of longitude continually become less, till at the poles their length is nothing.

Position on the Earth. The latitude and longitude being known, the exact position of a place is known, for it must be where the meridian on which latitude is measured crosses the parallel on which the longitude is measured. These two measurements serve the same purpose in describing the position of a place on the earth's surface, as measurements of the distance from two walls in describing the position of an object in a room, such as a coin on the floor. If we know the distance from a side wall only, the coin may be anywhere in a line running along the floor at that distance; but if we know also the distance from an end wall, then it must be in the point where the two lines at these distances from the walls cross each other.

Right Ascension and Declination. We have seen that the position of a star in the heavens may be described by means of the two measurements, altitude and azimuth; it may also be described by two other measurements on the celestial sphere, which correspond to latitude and longitude on the earth or terrestrial sphere. These measurements are called DECLINATION and RIGHT ASCENSION. The distance of a star from the celestial equator, or equinoctial, is its DECLINATION, and corresponds to latitude on the earth; and its distance from the celestial meridian, which passes through the celestial poles and a well-known point of the heavens called Aries, is its RIGHT ASCENSION, and corresponds to longitude. Declination is measured from the equinoctial along a celestial meridian; right ascension is measured from the point Aries along the equinoctial.

The Zones. Some of the more important of the circles parallel to the equator, or parallels of latitude as they are called, demand attention. At 23½° from each pole, and therefore at 66½° on each side of the equator, are the polar circles—the North Polar and the South Polar,—or, as they are often called the Arctic and Antarctic circles. Again, at 23½° north of the Equator is the northern tropic, or tropic of Cancer, and at 23½° south of it, the southern tropic, or tropic of Capricorn. These four parallels divide the surface of the earth into ZONES, or belts. Between the tropics is the TORRID zone; between the tropics and the polar circles lie the TEMPERATE zones—north and south; and within the polar circles, surrounding the poles, lie what are called the FRIGID zones. The names tell the prevailing climate in each zone.

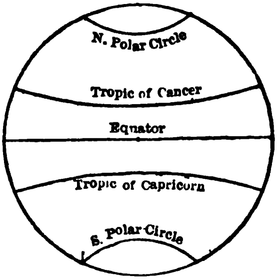

Fig. 4.—Equator, Tropics, and Polar Circle.

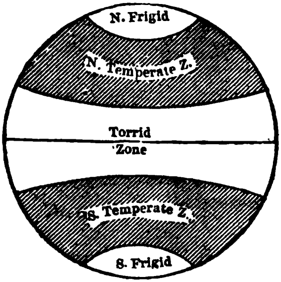

Fig. 5.—Zones.

Attraction of the Earth. Since the world is round, it may be asked, why do not the people fall off who live on the other side of it from us, and whose feet must be upwards and heads downwards? To answer this we must consider what falling means. It means coming down to the ground; and as we, when we fall from a height, come to the ground, so do they who live on the other side of the world.

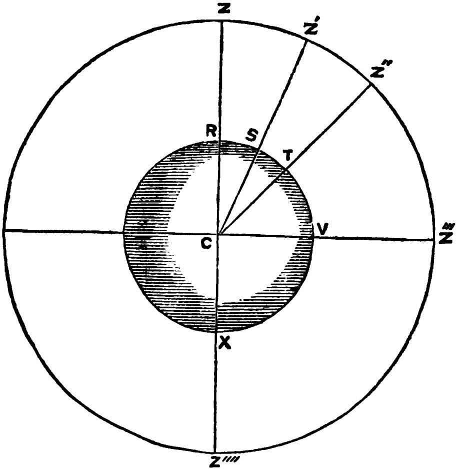

Fig. 6.—Convergence of Vertical lines.

R, S, T, V, X, places on the surface of the earth.
Z, Z′, Z″, Z‴, Z⁗, their respective zeniths.
ZR, Z′S, Z″T, Z‴V, vertical lines along which bodies fall towards C, the centre of the earth.
X, antipodes of R.

The truth is, the earth has the power of drawing the bodies which we call heavy towards its centre, and towards this they all fall till they are stopped by the ground. A line from any height above the earth to its centre is called a VERTICAL line, or merely a

VERTICAL, and along such a line falling objects must pass till they reach the ground—along it, too, a plumb line hangs. To anyone anywhere *down* means towards the earth's centre, and *up* means along the vertical away from the centre towards the point of the sky above our heads. Since the verticals converge to the centre of the earth, they diverge from each other in passing from the centre to the zeniths of different places, and will point to parts of the heavens as many degrees from each other in the celestial sphere, as the places are separate from each other in the terrestrial. Down and up are, therefore, merely relative terms; and those who live exactly at the opposite part of the world from us, our ANTIPODES as they are called, are as much on the upper surface of the earth as we are.

EXERCISES.

Give proofs that the earth is round. Define the following terms:—Axis, poles, equator, horizon, zenith, nadir, meridian. Distinguish between a great and a small circle in a sphere. Distinguish between the celestial and the terrestrial spheres. Distinguish between the terrestrial and the rational horizons. How is a circle divided? What is the relation between arcs of a circle and angles? Describe the mariner's compass. Define altitude and azimuth. What is latitude? longitude? What is the use of these measurements? Define right ascension, and declination. Name the different zones of the earth. What parallels of latitude bound each zone? Show that 'down' and 'up' are relative terms. What is a vertical line?

II.

MAGNITUDE OF THE EARTH.

Modes of Measurement.

The earth being a sphere it would be easy to tell the size of it, could we descend into its bowels and measure the distance from the surface or circumference to the centre—that is, measure the radius of it. For the radius being doubled, forms the diameter; and the diameter of a sphere being multiplied by 3.1416 gives its circumference; and from these all other measurements of the sphere can be found. Or again, if we could travel round it along any meridian, or along the equator, we might measure the circumference of either of these circles directly. This, indeed, cannot be done, but there still remains the fact, that as the circumference of a sphere is a circle, or 360°, if we could but measure one degree of that circle, then by multiplying the length of that one degree by 360 we should learn the length of the whole circumference. The question of measuring the earth, then, resolves itself into finding the length of one degree. The difficulty lies in knowing when we have gone over one degree, or $\frac{1}{360}$th part of the earth's circumference, so as to measure it.

Measurement of a Degree by time.

By considering that the earth turns round a complete circle, or 360°, in 24 hours, and therefore 15° in one hour, or 1° in four minutes of time, we can judge that any two places on the equator whose meridians are crossed by the same star, but the one four minutes later than the other, must be 1° of longitude from each other. The one must be so far west of the other. We might then measure the actual distance between these places, and having thus found the actual length of 1° on the equator, multiply it by 360 for the whole circumference of the earth at the equator.

By the height of a star.

Or, since the space of the heavens and that of the earth are concentric, it follows that if we can move along any meridian till a star at the zenith of our starting point is one degree below it—then, since we have made our zenith change 1° in the heavens we must have gone over 1° upon the earth. We might now retrace our steps and measure the distance passed over; and, could such a thing be done, we should find that this distance is about 69½ miles; so that the whole circumference of the earth would thus be shewn to be 69½ × 360, or in round numbers 25,000 miles.

Triangular method.

The actual mode of measuring the circumference of the earth somewhat resembles this. At no part of the earth, perhaps, is it practicable to move along 1° without departing from the meridian line. Inequalities of the surface, rivers, forests, marshes, and mountains block the way. A short line is first carefully measured in a level country. This is called a base line. Then starting from this line, the lengths of the lines, and the angles formed by the lines which join a number of accessible points on either side of the meridian, are measured; and from these measurements, by the known rules regarding the sides and angles of triangles, the exact distance between two far remote points on the same meridian is at length found. Suppose that a vertical, or plumb line at one of these remote points of the meridian points upwards to a certain star in the heavens, while the vertical at the other points 36° south of that same star, then the two remote points are 36° from each other, and the distance between them is clearly $\frac{1}{10}$th of the whole circumference of the earth.

Difference of Degrees of Latitude.

If the earth were exactly a sphere this would suffice, and any number of degrees measured anywhere on its surface would always be equal to the same number measured anywhere else. But exact measurements have shewn that a degree measured near the equator is something less than one measured near the poles. One measured in Sweden is two-thirds of a mile longer than one at the equator; one in Scotland 100 yards longer than one in the South of England; one in Russia 800 yards longer than one in India. It follows from these facts that the earth is not exactly spherical, but is flattened as we approach the poles. The diameter is longer across the equator than from pole to pole, and a man on the ground at the pole is therefore nearer the centre of the earth than one on the ground at the equator. Exact measurements give the equatorial diameter as 7925.604 miles, and the polar as 7899.114. There is thus a difference of 26.49 miles, so that the distance from the poles to the centre of the earth is about 13¼ miles less than that from the equator to the centre; and the flattening at the poles is about $\frac{1}{299}$th of the radius at the equator.

Irregularities on the earth's surface.

By considering these measurements it is easy to see that the high mountains and deep hollows which we know to exist on the earth's surface do not really contradict the statement which may now be made, that the earth is a sphere or globe somewhat flattened at the poles—a figure of which an orange gives a good idea, except that the flat parts of the orange are too flat. The very highest mountain on the earth is not quite 5 miles above the sea level, that is, not quite $\frac{1}{800}$th part of the earth's radius. On an artificial globe six feet in diameter, this mountain would have to be raised from the surface only $\frac{1}{25}$th of an inch—a roughness that would not be easily perceived, and would not affect the roundness of the globe.

EXERCISES.

What is the ratio of the circumference to the diameter of a circle? If the length of a degree of a circle were known, how could the whole circumference be known? How might the length of a degree on the equator be found? How may it be found along any meridian? What is the average length of a degree on a meridian? How great is the circumference of the earth in round numbers? By what process is a portion of a degree on the earth's surface actually measured? How is it found what part of the whole circumference the portion actually measured is? Give the exact lengths of the polar and equatorial diameters of the earth, and their difference. Show that the heights and hollows on the earth's surface do not affect its roundness as a whole.

III.

ROTATION OF THE EARTH.

That the earth rotates on its axis is proved by:—

Proofs.

(1.) The apparent daily motion of the sun, moon, and most of the stars from east to west.

(2.) The alternations of day and night.

(3.) The flattening of the earth at the poles, and the consequently greater weight of the same object at the poles than at the equator.

(4.) Foucault's pendulum and gyroscope.

(5.) The trade winds.

Apparent movements of the stars.

The sun, moon, and most of the stars, appear to go round from east to west every day, but this motion of theirs is only apparent, and is caused by our going round on the earth in a contrary direction; as trees, houses, and telegraph posts appear to us to be flying backwards, while we ourselves are really going forward in a railway carriage. We are unconscious of the movement of the earth, because all things on it move along with us; as in the cabin of a smoothly sailing ship we are unconscious of the ship's movement, because all things in it move with us, and lead to the delusion that the objects on shore are going the contrary way.

Day and Night.

The alternations of day and night are proofs that the earth rotates once every 24 hours, since they are the consequences of that rotation, and have been traced to no other cause. By reason of it, each place on the earth is brought, at one part of the 24 hours, round in front of the sun, and then has day; the places on the opposite side of the earth are at the same time turned away from the sun, and then have night.

The heavens do not revolve.

But why may it not be that the sun, moon, and stars move round the earth every 24 hours, the earth being at rest? Because the sun, as we shall learn by and by, is more than a million of times larger than the earth, and 91 million of miles away from it. To move round the earth daily, keeping always about such a distance from it, the large body of the sun would require to move at the rate of about 70,000 miles every second; whereas, for the comparatively small earth to turn round on its axis daily before the sun, no part of its surface need move more quickly than at the rate of about 1,000 miles per hour, or about seventeen miles per minute. The idea that, for the sake of giving light and heat to all parts of the earth, the sun should move round it, is like that of making a fire revolve round a fowl in order to cook it, instead of turning the fowl before the fire on a spit. Galileo, the famous astronomer, compared the notion of the sun's revolving round the earth to that of making the land turn round, in order to shew Venice from the cupola to a traveller, rather than cause the traveller to turn his head.

Flatness at the Poles.

The flattening of the earth at the poles affords proof that the earth rotates. For a fluid sphere turning rapidly round would assume such a flattened shape as the earth has; and there is good reason to believe that the earth was once a spherical mass of heated fluid. Because of this deviation from the spherical shape we have seen that the surface of the earth at the poles is nearer the centre by 13 miles than that at the equator; we have seen, too, that all objects are drawn to the earth by a force tending to the centre, and stronger the nearer they are, on or above the surface, to that centre. The force with which objects are thus drawn towards the earth's centre constitutes their weight; and this is consequently greater at the poles than at the equator, since at the poles bodies are nearer the centre than at the equator. From this increased force of the attraction to the earth's centre, it has been calculated that a heavy body weighs more by $\frac{1}{590}$th part at the poles than it would do at the equator.

Centrifugal Force.

But the rotation of the earth also lessens the weight or pressure of bodies by means of what is called centrifugal force—namely, that force by which objects moving in a circle tend to fly off in a straight line at right angles to the radius of the circle of movement, so soon as the force which keeps them moving in a circle ceases. For example, a stone flies off from a sling when the cord which kept it revolving round the slinger's arm is slipped. This *offward* pressure, so to speak, not *upward* pressure let it be noticed, acts upon all objects at the surface of the earth, and the more strongly the larger the circle in which they revolve in a given time. It is clear that objects on the large circle of the equator must have a greater offward pressure than those on the small parallels of latitude, since all objects on the earth describe daily circles in the same time, namely, that in which the earth revolves. At the poles the length of the circle of revolution is nothing, at the equator it is nearly 25,000 miles. The centrifugal force at the equator lessens the downward pressure of any object by $\frac{1}{289}$th part of that which it would have at the poles, where there is no centrifugal force; so that from this cause a body weighing 289 lbs. at the poles would weigh only 288 lbs. at the equator.

Whole difference of weight.

Now, if we add the $\frac{1}{590}$ of diminution of weight at the equator because of the greater distance from the centre, to the $\frac{1}{289}$ of diminution because of the centrifugal force, we get the fraction $\frac{1}{194}$ (since $\frac{1}{590} + \frac{1}{289} = \frac{1}{194}$) for the whole increase of weight at the poles on account of the rotation and consequent shape of the earth. Therefore 194 lbs. at the poles will weigh only 193 lbs. at the equator; and it has been calculated that were the earth to rotate with about 17 times its present speed of rotation, bodies at the equator would have no weight at all, for the offward pressure of centrifugal force would then counteract the downward pressure to the centre of the earth.

Foucault's Pendulum.

There is a beautiful experiment of the French astronomer, Foucault, which proves, and, as it were, lets us see that the earth rotates. A heavy, freely-moving pendulum is set swinging from a lofty ceiling in a given plane of oscillation—directly over a straight line drawn in black on the floor. After a while the pendulum, without having been touched, swings in a direction slightly oblique to the line on the floor, and its plane of vibration becomes more and more oblique as time goes on, till the different courses of its vibrations have formed a circle round the black line. The reason is, that the pendulum by what is called its inertia, or powerlessness to change the direction of its motion, swings on in the direction in which it was set swinging, while the earth turns round under it. Fields, woods, and towns revolve with the globe on which they are fixed; the pendulum keeps unchanged its original direction. If such a pendulum were hung over the pole of the earth, the black line under it would really move round in a circle in 24 hours; but, to the observer, unconscious that both he and the black line are rotating with the earth, it would seem as if the pendulum had been constantly changing its plane of vibration and had completed a circle of changes over the line. At the equator such a pendulum would shew no changes in the plane of vibration, for there the

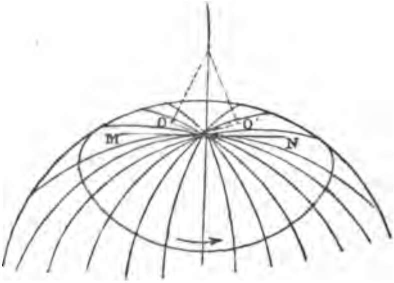

Fig. 7. -Pendulum experiment at the Pole.

OO, Curve of oscillation.—MN, line above which the pendulum vibrates.

earth in its rotation would not be carried round under it, but would carry the plane of vibration along with it. At places between the equator and the poles, the times in which the planes of vibration of such a pendulum complete a circle are longer the farther from the poles. At the latitude of 30° a circle is completed in two days; at London in 30 hours; at Paris in 32.

Gyroscope. Foucault also invented the Gyroscope, which proves the same thing, and makes it evident to the senses. This is a wheel with a very heavy rim, turning easily on horizontal pivots fixed on the inner sides of a ring. The ring turns on perpendicular pivots fixed into the framework of the instrument. The arrangement is thus like the gimbals of a ship's compass. The wheel set whirling in any direction but that of the earth's axis tends always by the great weight of its rim to keep in that direction, while the framework of the machine turns round with the earth on which it rests. Thus the wheel would describe a circle within the frame in 24 hours at the pole, and takes a longer time to do so near the equator. To set the wheel whirling in the direction of the earth's axis—namely, from north to south, or the reverse—could shew nothing; since, as we shall see, that axis, like the plane of the wheel's motion, is unchangeable, and the two directions would continue to coincide.

Trade Winds. The trade winds are results of the rotation of the earth, and therefore proofs of the fact that it rotates. Two-thirds, indeed, of the force of all the winds of the world is force given out by the globe as it rotates. The great heat of the torrid zone expands the air; it rises, and cold air from the north and the south rushes in to occupy the place of the expanded air. Were the earth fixed, we should thus have a constant wind from the north—that is, a north wind, blowing along the meridians in the northern hemisphere—and a constant south wind in the southern hemisphere. These winds would be constant, since the heating of the tropical regions by the sun is constant. But the earth rotates on its axis from west to east, and places on parallels of latitude near the poles have much less speed eastward than places on parallels near the equator.

Now since, in the northern hemisphere, the air from the polar regions is carried southward, having only the velocity eastward of the regions from which it came, it has less speed eastward than the places at which it arrives, and therefore it lags behind; or the meridians, as it were, slip along below it on their course from west to east. The wind from the north cannot therefore continue to blow along the meridians; it must cease to be a direct north wind, and from its being left behind in the west will become a wind from the north and east—that is, a north-east wind.

In the same manner, the direct south wind from the pole in the southern becomes a south-east wind. As the parallels do not differ greatly in length near the equator, there is but little increase of this eastward tendency, and the winds from the north and south die out, leaving a region of calm about the equator. The constant winds from the north-east in the northern hemisphere, and from the south-east in the southern, are called the Trade Winds.

Anti-trade Winds. The air which rises at the equator goes towards the poles. Were the earth still, there would thus be in the upper regions of the atmosphere a south wind in the northern hemisphere, and a north wind in the southern. But, as the earth revolves, the speed of this wind eastward, or from the west, is much greater than that of the places to which it successively approaches. As it approaches cooler regions it cools, and begins to descend; and between the 35th and 60th parallels shews itself as a south-west wind in the northern hemisphere, and as a north-west wind in the southern. These winds are sometimes called the Anti-Trades, or return Trade winds; they prevail on the Atlantic and Pacific Oceans.

The Monsoons. In the Indian Ocean the north-east trade wind blows even to the equator during the winter half-year of the northern hemisphere, that is, from October to April. But during the summer half-year, or from April to October, a south-west wind blows in this ocean. The air, then, over the continent of Asia is heated, expanded, and raised; and the cooler air from the Indian Ocean presses from the equator northwards towards the mainland. It thus passes continually towards shorter parallels of latitude, and to places moving eastward with less velocity than it has. Therefore it becomes to these regions between the equator and the continent of Asia a south-west wind. These north-east and south-west winds of the Indian Ocean are called MONSOONS; and, like the trade winds, are both results and proofs of the rotation of the earth on its axis.

EXERCISES.

State five proofs of the earth's rotation. What causes the apparent movements of the starry sphere? Give illustrations to show that it is improbable that the heavens revolve ronnd the earth. How, and to what extent, is the weight of objects affected by the shape of the earth at different parts of it? How, to what extent, is the weight of objects affected by centrifugal force? In what direction does centrifugal force act? What is the amount of the whole diminution of weight at the equator, from increased attraction and diminished centrifugal force at the poles? Describe the apparent movement of Foucault's pendulum: (a) at the poles; (b) at the equator; (c) at a middle latitude. Describe briefly Foucault's gyroscope. Show how the trade winds and the monsoons result from the rotation of the earth.

IV.

LONGITUDE AND LATITUDE.

Finding the Longitude.

Longitude, as we have seen, is the distance of a place east or west of a first meridian. Any meridian may be chosen for the first—that which passes through Paris, New York, or Greenwich. The British geographers choose that which passes through Greenwich. Since the earth turns completely round, from west to east before the sun in 24 hours, it is clear that 360° of the earth's surface pass directly in front of it during that time; or 180° in twelve hours; 90° in six hours; 30° in two hours; and 15° in one. The meridian, therefore, of places that are 15° east of the first meridian will come in front of the sun one hour before the first meridian itself. All places have midday when the earth by its rotation brings them directly in front of the sun; and, therefore, a place 15° east of the meridian of Greenwich will have 12 o'clock one hour before it is 12 at Greenwich—namely, when it is only 11 there, and of course when it is only as yet 10 o'clock at places 15° west of Greenwich. Therefore, for every hour of difference in the time of two places as regulated by the midday sun, there must be 15° of difference in their longitudes; and proportionally, for every four minutes of difference there must be a difference of 1° in longitude. The finding of longitude, then, consists in finding exactly the difference between the time at a place of which the longitude is required and that at Greenwich, or any other place on the first meridian.

Examples.

Thus, if it be 6 o'clock in the evening at Calcutta when it is 12 noon at Greenwich, the longitude of Calcutta is 90° (6 × 15°). The longitude, is east because it is later in the day, and the sun has passed over Calcutta on its daily course from places east to places west. So, if it be 7 in the morning at New York, when it is 12 at Greenwich, the longitude of New York is 75° (5 × 15°) west. It is west, because the sun in its daily course has yet to bring noon there.

Relation of Longitude to time.

The question of longitude resolves itself therefore into how to find the difference of time as told by the clocks of two places at the same absolute moment of time—the moment now passing at both places. This may be done by carrying a perfectly going watch, or chronometer, set say to Greenwich time, to the place whose longitude is required, and comparing it with the time shewn on the clocks there. Or, it may be done by watching the exact moment on the clocks of both places at which some event happens, that can be seen at both places at the same moment. Such events are eclipses of the sun, or moon, or of Jupiter's satellites. Of a similar nature, too, are telegraphic signals made from one place to the other; or the firing of rockets on a day agreed upon.

Lunar Method.

But longitude is best and most conveniently found at sea, by observing the moon's place among the stars. The distance of the moon from well-known stars, or the moment of her hiding a star, is published yearly for every three hours, three years in advance; and the sailor, observing a given distance of the star and the moon, or the hiding of the star at a given moment of his time at sea, can find from the almanac the exact time of the same distance between moon and star, or the same covering of a star in Greenwich time. Allowing 15° for every hour of difference of the two times, and 1° for every four minutes, his longitude is now easily calculated. This is called the lunar method of finding longitude.

Finding the Latitude by the Polar Star.

Latitude may be found by observation of the polar star. If we were exactly at the pole, at latitude 90°, the pole star, which is a star very near the actual pole, would be in our zenith, or 90° above the horizon. Again, if we were at the equator, where our latitude is nothing, the pole star would be on the horizon—no height above it. If now we advance 1° northward, the pole star would appear to have risen 1°; if we advance 2°, it would appear to have risen 2°, and so on, till when we have advanced 90°, the star's height, or altitude, is also 90°. Thus, as many degrees as we are from the equator, so many is the pole star above the horizon; and, therefore, the latitude is always the same as the altitude of the pole.

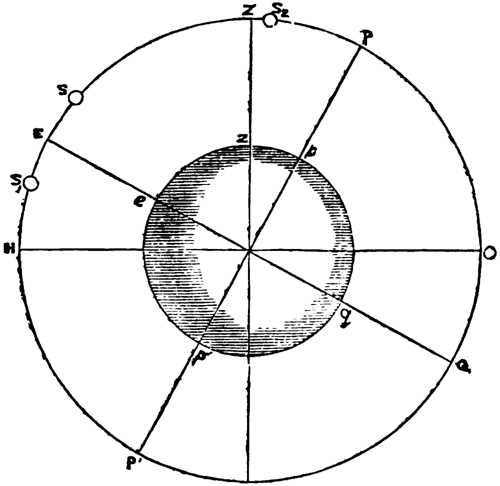

Fig. 8.—Modes of finding latitude.

The Inner circle represents the earth. The Outer circle represents the celestial sphere. *z*, a place on the earth. Z, its zenith. EZ or *ez* the latitude of observer. P,P′, p,p′ the celestial and terrestrial poles. HO, the horizon of the place *z*. EQ, the equator. S,S,S_2, different positions the of sun.

From E to P is 90°, and from O to Z, is 90°; from Z to P is part of both, and taking it away, EZ the latitude equals OP the polar height. SE, S_2.E, S E are different declinations; and the latitude EZ is either SZ+ES, or S_1Z−ES, or ES_2—ZS_2; that is, the declination added to, or subtracted from the zenith distance; or the zenith distance subtracted from the declination.

By the Zenith, distance of the Sun.

But, again, since our latitude is always the distance of our position from the equator, in degrees of the earth's circle, and since the circles of the heavens and the earth are concentric, the distance of the point above our head, our zenith, from the equinoctial, or celestial equator, will be the same number of degrees as our latitude. Now, if we observe the distance of the sun below our zenith at noon, and learn from the almanac its declination or distance above the equinoctial, then by adding these distances we get the distance of our zenith from the equinoctial and this is our latitude. Should the sun happen to be farther from the equinoctial than our zenith is, that is, should its declination be greater than our latitude, then we must subtract its zenith distance from its declination, and we get our zenith distance from the equinoctial of that is our latitude. Or, should the sun be south of the equinoctial, as it is in winter, while we are north of it, then we must subtract its declination from its zenith distance, and again we get the distance from our zenith to the equinoctial, —our latitude.

EXERCISES.

What connection has the finding of longitude with the rotation of the earth? How is time connected with distance in longitude? By what means may the difference of time at two places on different meridians be found? Describe the lunar method of finding longitude. How may latitude be found by means of the polar star? How may it be found by the zenith, distance of the sun: (a) When the sun is south of the equinoctial and the observer north of it? (b) When the sun and the observer are both north of the equinoctial; but (1.) the sun nearer the equinoctial than the zenith of the observer; and (2.) the zenith of the observer between the sun and the equinoctial? (c) When the sun is on the equator?

V.

ANNUAL MOTION OF THE EARTH.

Earth's orbit elliptical.

The earth, besides turning on its own axis once every 24 hours, describes a course round the sun from west to east through the heavens, and completes it in exactly a year. This course is not circular, but forms a curve called an ELLIPSE, which may be described as a kind of flattened circle, some parts of which are nearer the centre than others. Thus, the motions of the earth, turning on its axis and going round the sun, resemble those of a carriage wheel revolving and going forward at once, or those of a person waltzing, who whirls round and makes the circuit of the ball-room at the same time.

Proofs of Annual motion.

That the earth completes a circuit round the sun in a year is proved by the following circumstances:—

(1.) The sun appears every year to complete a circuit among the stars.

(2.) The variations of the seasons, and the varying length of day and night, are consequences of the earth's annual motion round the sun.

(3.) Certain changes occur in the apparent movements of the planets, which can only be explained on the supposition that the earth moves round the sun.

(4.) The light of the planet Jupiter and its moons is later of reaching the earth at certain times than at others.

(5.) The fixed stars alter their apparent positions in correspondence with the earth's changing positions in its orbit round the sun.

Sun's apparent circuit.

The apparent course of the sun among the fixed stars can be traced by careful observation. While going down in the west on the 1st day of January, for example, it sets along with a certain star visible near it. On the 2nd of January the star will have set before the sun; the sun has apparently moved eastward since yesterday, and now sets with other stars. On the 3rd of January it will set along with stars still more to the east. And if we had chanced to observe what stars were rising in the east as the sun went down on the evening of the 1st of January, we should find by watching that on the 1st of July, half a year from the beginning of our observations, the sun sets along with these. It appears, therefore, during this time to have moved half round the heavens among the stars, while rising and setting daily. It will still, if observed, be found to change to stars a little farther east; and by next 1st of January will again set with the same stars as on that day last year. Thus, in a year, it appears to have described a circuit among them. This appearance of movement might, indeed, be a real movement, but would in no way appear different if it were only a movement of the earth round it; and the fact that the sun is above a million times larger than the earth renders it, as we have seen before, much more probable that the earth moves round the sun, than that the sun moves round the earth.

Experiment. To understand the sun's apparent change of place among the stars, let us make a simple experiment. Let us set a lighted lamp on a table in the centre of a room, the walls of which are covered with pictures, and let us begin from the western wall to walk round the room. If when starting we look towards the lamp, we shall see it, as it were, shining among the pictures on the eastern wall. Let us now walk along the northern wall; the lamp in the centre will then appear against the pictures on the southern wall, and if we could have been unconscious of our change of place we might have thought that the lamp, not we, had been going round. At the eastern wall we should see the lamp against the pictures on the western, and at the southern among those on the northern, till when we had completed our course round the room, it would again have its first position among the pictures on the eastern wall. These are exactly the same appearances as would occur were we to station ourselves in the centre of the room, and the lighted lamp to be carried round us. In a similar way the sun at rest in a known point within the earth's orbit, appears to us on the moving earth to change its place among the starry groups, from day to day, and from month to month.

Ecliptic.

The sun moves always along the same line, and among the same groups of stars, each successive year. Its apparent track is called the Ecliptic, or sun's path; though of course, it is really the earth which has a path; and while it is in any one part of that path, the sun seems to be in the opposite part, as to us at one wall the lamp seemed to shine amongst the pictures on the opposite one. The stars among which the sun passes yearly form well-known groups or constellations—each group being fancifully considered to represent a certain object, generally an animal.

Zodiac. The belt of the heavens on each side of the ecliptic which these groups occupy is called the *Z*odiac, and the groups of stars are called the signs of the zodiac. Thus the ecliptic, like the equinoctial is, a large circle in the sky—the equinoctial being the extension of the earth's equator to the celestial sphere—the ecliptic the circle in the celestial sphere which the sun seems to traverse. These two circles occupy different positions and cross or cut each other at opposite points of the heavens. They, of course, coincide at the points of crossing or intersection ; but, at the parts where they are widest asunder, the space between them is 23½° of the celestial sphere. The ecliptic is in one part, therefore, 23½° north of the equinoctial, and in another 23½° south of it.

Equinoctial points. The sun is never out of the ecliptic, that being its path; but twice a year it is seen also on the equinoctial ; namely, when it is in those points of its path which cross that line. When on the equinoctial in spring it is said to be in the point Aries ; it passes thence through one constellation after another north of the equinoctial, till in autumn it is again on that circle in the point named Libra. During the next half of the year it passes along south of the equinoctial back to Aries. Aries, then, and Libra, are points in the heavens, both in the ecliptic and in the equinoctial.

Constellations. The successive constellations, or signs of the zodiac are: Aries, the ram; Taurus, the bull; Gemini, the twins; Cancer, the crab; Leo, the lion; Virgo, the virgin; Libra, the balance; Scorpio, the scorpion; Sagittarius, the archer; Capricornus, the goat; Aquarius, the waterman; and Pisces, the fishes. When the sun is in the highest point of its apparent path above the equinoctial it is in Cancer; when in its lowest below, it is in Capricorn. The actual groups of stars so named do not now correspond with these names of the sun's positions, though they did so 2,200 years ago. We shall learn the reason soon.

Solstice and Equinox. Since the declination of a heavenly body means its distance from the equinoctial, the sun's declination on the 21st of March and 23rd of September when it is on the equinoctial is nothing. On the 21st of June its declination is 23½° north, and on the 21st of December 23½° south. The points where the sun, or the sun's path, crosses the equinoctial are called the equinoctial points, and the times of crossing are called respectively the vernal and the autumnal equinox. The interval between the sun's leaving an equinoctial point and returning to it is called a TROPICAL YEAR. The two points where the sun is at its greatest distance along its path from the equinoctial are called the solstices—respectively the summer and the winter solstice.

Celestial latitude and longitude. The sun's distance from the point Aries along its own path is called its longitude. For the ecliptic is to the celestial sphere what the equator is to the earth,—the circle from which latitude, and round which longitude is measured. In the celestial sphere distance from the ecliptic is latitude, and distance around it from the first point of Aries is longitude. The sun can never have latitude, since it can never be at a distance from its own path; its longitude at the summer solstice is 90°; at the point Libra, 180°; at the winter solstice, 270°.

Causes of the Seasons.

The variations of the seasons are consequences of the earth's annual orbit round the sun, and therefore proofs of it. The changes of the seasons, in fact, depend upon three causes, (1) the annual orbit; (2) the fact that the earth's axis is inclined to the plane of its orbit; and (3) the fact that the axis preserves invariably the same direction in space.

1. Elliptical Orbit of the Earth.

The orbit which the earth describes is, as we have said, not a circle, but an ellipse—an oval figure, as artists would say. A circle has all its diameters alike in length, but an ellipse has two chief diameters, or axes, as they are called, of which the one, called the MAJOR AXIS, is longer than the other, called the MINOR AXIS. Two points on the major axis at equal distances from the centre of the ellipse are called the FOCI. The sun is placed in one of the foci of the ellipse formed by the earth's orbit, distant from the centre by about $\frac{1}{60}$th of half the major axis, or above 1½ million of miles. This distance from the centre is called the sun's eccentricity; and owing to the sun being so placed, the earth is at one part of its orbit three million of miles nearer the sun than at the opposite part of it. This, strange to say, happens in our winter;—but, as we shall see, the position of the northern parts of the earth in summer is such as to cause the increase of heat then, in spite of the greater distance of the earth from the sun. When the sun is nearest the earth it is said to be in PERIHELION; when at its greatest distance, it is said to be in APHELION.

2. Inclination of the Axis of the Earth. The axis on which the world rotates is inclined to the plane of its orbit; that is, it leans towards the space within the earth's orbit, or the extension of that space, and leans towards it by 23½° off the perpendicular—exactly the number of degrees by which, in the celestial sphere, the equinoctial is inclined to the ecliptic. This axis, too, leans always in the same direction, so that the earth proceeds round the sun much in the same way as a top moves, which runs forward and leans to the ground as it spins. But the earth's axis points always the same way, in whatever part of its orbit the earth may be.

3. Parallelism of the Axis.

We may now easily construct a diagram to illustrate the changes of the seasons and the different lengths of day and night. Draw an ellipse for the earth's orbit. Place the sun nearly in the centre. Draw next four circles at four opposite points of the orbit to represent the earth in four different parts of its yearly course, namely, its positions on the 21st March, 21st June, 23rd September, and 21st December. Draw NS to represent the axis of the earth in each of the four circles, inclined 23½° to the plane of the elliptical orbit, so that the four lines NS shall be parallels, and therefore all point in the same direction. Draw also the equator, chief parallels, and meridians in each figure. Now shade each figure so that the half of the earth which is turned away from the sun shall be dark, and the half nearest it bright.

The circle nearest the observer representing the position on 23rd September, in the foreground, so to speak, of the diagram, must have the whole of its dark side turned towards him, because the sun shines on the side of the earth which he cannot see. The figure in the distance representing the position on 21st March has the whole of its bright side towards him, because the sun is in the middle ground of the diagram,

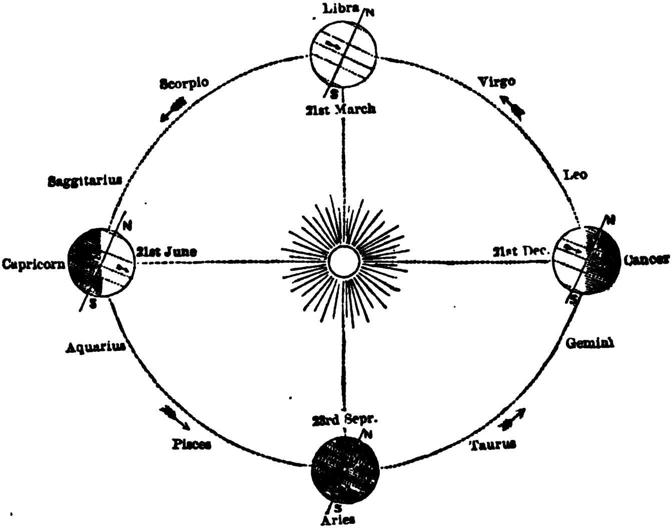

Fig. 9.—The Seasons, and Signs of the Zodiac.
On Sep. 23, the earth as seen from the sun is in Aries, while the sun as seen from the earth is in Libra. June 21, earth in Capricorn, sun in Cancer. Dec. 21, these positions reversed. March 21, earth in Libra, sun in Aries. The arrows show the direction of the earth's daily rotation, and annual orbit.

between him and it. On the 21st March the sun's rays fall so that the edge between the light and dark sides of the earth, the CIRCLE OF ILLUMINATION as it is called, passes through N and S, the north and south poles. It is evident that as the earth turns round daily while in this position, every point on its surface will be exactly half of the 24 hours in the light side, and the other half in the dark side. All places will, therefore, at this time, have 12 hours day and 12 hours night. The same will be the case in the position of the earth on 23rd September.

But in passing from the one to the other position, the earth midway between them takes the position in regard to the sun which it has on 21st June. The figure representing this position shows that the edge between the light and dark sides of the earth does not pass through the poles N and S, because of the inclination of the axis; its northern end being now turned towards the sun, and the southern end turned away from it. The sun's light now reaches a point 23½° beyond the north pole, and falls short of the south pole by the same amount. In this position, as the earth rotates on its axis, the parts round the north pole do not in any part of the 24 hours pass out of the lightened hemisphere, and have therefore perpetual day; while the parts round the south pole, since they do not during a rotation pass out of the darkened hemisphere, have perpetual night. Half of the equator, however, it will be observed, is in the light, and half in the dark hemisphere, so that all places on it have their day and night equal in length. But the places on latitudes between the equator and the bright circle round the north pole are longer in the light than in the dark side of the earth during one daily rotation, hence their days are now longer than their nights; while the places in latitudes between the equator and the darkness surrounding the south pole are more in the dark than in the light hemisphere during a rotation, hence their nights are long and their days short. In this position we have the summer of the northern, and the winter of the southern hemisphere.

All this is reversed in the earth's state on the 21st December. There the parts about the south pole have continuous light, and those about the north pole continuous darkness, as the earth rotates. There, too, the parts on the equator are still equally long in the light and in the dark; but all parts between the equator and the circle 23½° from the north pole are longer in the dark than in the light during a rotation, and have short days, and long nights; while, for the opposite reason, the parts between the equator and the south polar circle have long days and short nights.

Day and Night in different latitudes.

It is plain, too, in the figures for 21st June and 21st December, that the further from the equator, or the nearer the polar circles a place is, the greater is the disproportion between the times of passing through the light and dark sides of the earth; and hence the greater the difference between the length of the days and nights. Within the polar circles the days and nights are months long; at the poles themselves, one day and one night last a year. The figures for 21st March and 23rd September represent the earth's position at the time of the equinoxes; those for 21st June and 21st December, the position at the time of the solstices; and the parts of its orbit in which it is at these times are called the equinoctial and solstitial points.

Twilight. When a place on any parallel of latitude passes out of the light hemisphere into the dark one, night does not come at once; and day appears before a place passes out of the dark into the light hemisphere. Every one is familiar with the twilight and the dawn. They are caused by the reflection of the sun's rays. When the sun has set, its rays can no longer reach us directly. The spot on which we stand has, so far as it is concerned, passed out of the light hemisphere. But for a time we can still see its rays gilding the mountain tops above us, because they can reach these, though not us in the valley. And even after the mountains have become sombre, the sun's rays can reach the air which lies above the peaks. Now everything upon which the sunlight falls, sends some of that light back to neighbouring objects—reflects it; and every neighbouring object reflects it to every other. Hence, after sunset, we have still a period of grey diffused light, and this continues till the sun has gone down below our horizon about 18°, after which no portion of the atmosphere above us is touched by its rays. So, in the morning when it is within 18° of the eastern horizon its rays fall once more on the upper air, which reflects them, and causes the first grey streak of dawn. By and by the rays reach the mountain tops, and their golden peaks diffuse them, till at length the sun itself rises, and the spot on which we stand passes fairly into the light hemisphere. As the sun's daily course round the rotating earth is always more directly overhead at midday within the tropics, than at places nearer the poles, it descends also more directly below the horizon after sunset. Hence it is sooner 18° below the horizon within the tropics than in latitudes higher than 23½°; and, therefore, twilight and dawn are much shorter in the tropics than in other regions.

Refraction. Yet another cause prolongs the day beyond the time of actual sunset: that is, the refraction of the sun's rays. By refraction is meant the power which the air and transparent fluids or solids have of changing the direction in which light travels through them. We always see objects in the direction in which the rays of light from them enter our eyes. A light may be behind us, but if we can turn its rays so that they will enter our eye, we shall see it, as it were, before us. Suppose the sun to be set, so that its rays cannot now reach us directly, but that some still fall on the air above our horizon, which can bend them downward to our eye, then we shall see the sun as if it were in the part above the horizon from which these rays proceed. By this means we see the sun at times nearly five minutes after it has set, and the same time before it actually rises. By nearly ten minutes, therefore, the actual day is lengthened in our regions. At the north pole the actual day of six months is prolonged nearly three days, or rather three times 24 hours, from this cause.

Planetary movements. The stars called planets, or wandering stars, get and deserve their name because of their apparently irregular movements in the celestial sphere. Sometimes they dart forward quickly among the fixed stars; then they seem to stand still for a while; then they go on again, or perhaps go backward, in a manner utterly perplexing at first, but perfectly capable of explanation and prediction when we assume that they are bodies like the earth, and that they, like it, move in definite orbits round the sun. Their movements, therefore, become proofs, by analogy, of the earth's annual orbit.

Their apparent irregularity.

Their apparent irregularity in the midst of the most perfect regularity of movement may be partly understood, if we think of a carriage moving on a dark night from west to east along a road at a distance from our position. Let some one at the same time carry continuously round the carriage a lighted lantern which we can see, though we cannot see the carriage itself. Now this lantern being carried regularly round the carriage would sometimes appear to us to go forward, then as it is carried round the front of the carriage away from us it would appear to stand still; then it would be lost behind the carriage, or probably its reflected light might be seen going backward. Again, in turning round towards us behind the carriage it would appear to stand still; and if we now move ourselves in the same direction as the carriage, and at the same speed along our route as the man moves who carries the lantern, then the lantern, though really advancing, will appear to us to stand still, because it does not alter its position in relation to us.

Velocity of light.

Of the planets, some are bodies much larger than the earth; and, as the earth has one satellite attending and going round it, they have one or more. Jupiter, a large planet, has four, which can be seen revolving round it; and which in their course go into the shadow of Jupiter at times, or are eclipsed, as we call it. It was of great consequence to know exactly the times of these eclipses, and Römer, a famous astronomer of the 17th century, set himself to calculate these times in minutes and seconds. They could all be calculated exactly; but to Römer's astonishment his calculations never agreed with the actual times of the eclipses. Sometimes they occurred 8 minutes 13 seconds too soon; sometimes as much too late.

The cause of this Römer at last ascertained to be that the earth in its course round the sun comes sometimes between the sun and Jupiter, and is then at its nearest position to Jupiter. But six months afterwards, when the earth has gone half round its course, while Jupiter has moved very little, the earth is on the other side of the sun from Jupiter, and is therefore more distant from that planet than before by the whole diameter of its orbit. Sometimes, therefore, we see the eclipses of Jupiter's moons, or satellites, when we are near, and sometimes at a great distance, because of the earth's revolution round the sun. Since light takes time to travel through space, therefore it is that we see the eclipses of these satellites, when we are near the planet, earlier than when we are farther off by the whole breadth of the earth's orbit. Thus, Römer's observations prove that the earth has an orbit, and that light takes the time by which the eclipses occur too soon, added to that by which they occur too late, namely 16 minutes, 26 seconds, to cross the earth's orbit—a distance of twice 91 millions of miles.

Aberration of light.

Bradley, another astronomer, who lived half a century later than Römer, set himself to try whether he could not find some proof that the earth moved round the sun, by an apparent corresponding movement of the stars: as when we go forward in a railway carriage, objects appear to move backward. Bradley reasoned, and rightly too, that the stars should appear to move in the opposite direction to that in which the earth was advancing. The nearest of the fixed stars, however, is too far away for any such movement to be observed by such telescopes as Bradley had. But he observed something else, almost the reverse of what he had expected. Instead of going backward, he found that the stars were seen always pushed forward a little in the direction in which the earth is moving at the time. This he found was the effect produced upon the apparent places of the fixed stars by the earth's real movement round the sun, taken in connection with the fact that light requires time to travel through space.

To understand this, let us think what would happen should anyone standing by a railway, fire a loaded pistol directly at a passing carriage, and send a bullet through both sides of it. The holes in the sides will necessarily mark the course of the bullet through the carriage. We should find that although the bullet had been fired directly in front of the carriage, the hole on the off side was somewhat farther back than that on the near side. Any one in the carriage might conclude that the shot had come from a point ahead of the carriage. The truth is that the bullet, however quickly it went, took time to cross the carriage, during which time the carriage itself had moved forward. The result is a combination of the speed of the bullet with that of the carriage, and only a person who understood this could tell the right direction in which the bullet had come. Even so, we on the earth are moving round the sun at a rate of about 18 miles per second, while light is coming to us from the fixed stars at a much greater speed—about 186,000 miles per second. The ray from a fixed star hits the front of the eye, as the bullet does the carriage, but takes some time to cross the eye, as the bullet does to cross the carriage. But our eyes have the movement which the earth has, as it carries us round the sun, namely 18 miles a second, and therefore the ray strikes the retina, not as it would have done had the earth been at rest. The star is therefore made to seem somewhat in advance of its real place, in the same way as the pistol appears to have been fired more to the front of the carriage than was actually the case; for we always see objects in the direction which the rays of light from them have when they affect the retina.

The same thing is true for a telescope, as for the eye. During the time which the light from a fixed star takes to pass through it, the earth has moved forward, and therefore, in order to see the star, the telescope must be inclined ahead of the real place of the star. Because of this apparent change of place nearly all the fixed stars appear to describe a course ahead, corresponding to the course of the earth in its orbit. Those exactly on a level with the earth's orbit, that is in the same plane with it, appear to move back and forward as the earth advances and returns in its course. Those 90° from it describe a small circle; those less than 90°; a small ellipse. We have thus through Bradley's discovery, which has been named the ABERRATION OF LIGHT, a direct proof that the earth moves round the sun.

EXERCISES.

Give five proofs of the earth's annual motion round the sun. Describe the sun's apparent movement among the stars in a year. What is the ecliptic? the zodiac? What are the signs of the zodiac? What angle does the ecliptic form with the equinoctial? How often, and at what times, is the sun on the equinoctial? In what points of the celestial sphere is the sun then said to be? Name the six signs of the zodiac through which the sun passes between April 21st and September 21st? Between September 21st and March 21st of next year?

In what points of the celestial sphere is the sun at its greatest distance from the equinoctial? How many degrees is it then distant from the equinoctial? and what seasons then occur? What is a tropical year? What are celestial latitude and longitude? What is the longitude of the sun: (a) at the summer, and (b) at the winter solstice? What is its declination at these times? What is its right ascension at these times?

On what three causes do the changes of the seasons depend? At what distance from the centre of the ellipse formed by the earth's orbit is the sun placed? What is this distance called? In what season is the sun nearest the earth? What are perihelion and aphelion? How much from the perpendicular is the earth's axis inclined to the plane of its orbit? Illustrate by a diagram the causes of the seasons.

How is the north end of the earth's axis placed in relation to the sun: (a) in March, (b) in June, (c) in September, (d) in December? What is the cause of twilight? When does it cease? How does refraction of light lengthen the duration of daylight? What is the nature of the apparent movements of the planets, and how do they illustrate the annual movement of the earth? How does the velocity of light as shewn by the eclipses of Jupiter's satellites prove the annual movement of the earth round the sun? What is aberration of light? How does it prove the earth's annual circuit?

VI.

DAILY CIRCLES OF THE SUN AND STARS.

Position of the equator in the heavens.

The equinoctial always intersects the horizon of a place in the east and west points; and as the pole is always at the height of the latitude above the horizon, the equinoctial must always form a curve in the visible hemisphere of the heavens 90° from the pole. Thus, since the pole at London is always 51½° above the northern horizon, and the equinoctial 90° beyond, if we subtract 51½° and 90° from the whole celestial hemisphere 180°, we get 38½° for the constant rise of the curve of the equinoctial, above the southern horizon of London. Every place has its own horizon, but the equinoctial is the same circle for all; and therefore the equinoctial may either concide with the horizon as is the case at the poles; or it may be perpendicular to it, as is the case at the equator; or it may be inclined to it, as is the case at London.

Daily circles at the poles.

At the poles the stars about the equinoctial will be seen on the horizon; and since the observer revolves with the extremity of the earth's axis on which he stands, these stars will appear to go round the horizon in a circle, and to renew the same course every 24 hours: All the stars above the horizon will appear to describe circles parallel to these, but smaller the higher they are; till, at last, the stars very near the pole in the zenith, will describe very small circles indeed. The polar star will seem not to move at all. Thus, at the poles, the stars between the equinoctial and the visible pole, that is the stars in half of the celestial sphere, are seen daily performing the whole of their course. Place a globe so that the equator and the wooden horizon coincide, and make it revolve. The equator will represent the daily circle of stars on the equinoctial or horizon, and the parallels of latitude those of stars higher than the horizon; the end of the earth's axis, which does not move, will represent the pole.

Daily circles at the equator.

At the equator the half of the celestial sphere visible at any time will shew the north pole on the northern horizon, the south pole at the southern point of the horizon; while all the fixed stars pass round from east to west describing half a circle. Those passing over the zenith, being the stars on the equinoctial, describe the longest semi-circle. On the north and on the south the semi-circles are all parallel and perpendicular to the horizon; they become gradually smaller till they become nothing at the poles. If a globe be set so that the poles are on the wooden horizon, and made to revolve, the equator and parallels will represent the apparent daily course of the stars at the equator, where all the stars of the celestial sphere are seen in only half their daily circles.

Daily circles in a middle latitude.

At a middle latitude, the polar star remains fixed above the horizon at a height equal to the number of degrees of the latitude. The stars near it describe small circles round it every 24 hours, in a course oblique to the horizon. The highest point of their course is called their upper culmination; the lowest, their lower culmination. Beyond the stars which just touch the horizon at their lowest culmination are stars which describe parts of a circle, the larger the nearer the pole, till on the equinoctial their path is exactly half a circle. Beyond the equinoctial to the extreme south of the horizon the portions of daily circles described lessen, till at the south pole they become nothing. Thus the stars not more distant from the pole than the horizon is, are seen in the whole of their daily course; those at the equinoctial in half of it; those between these positions in more than half; and those between the equinoctial and the opposite pole in less than half.

Daily circles of the sun.

The sun describes daily a different course in the heavens, and every day that course is along the same circle to all parts of the earth, but these daily circles are seen differently from different places. On the 21st of March the sun rises exactly in the east and for that day its course is exactly above the equator. On the 22nd it rises a little to the north of east and goes round a circle somewhat to the north of the equinoctial. On the 23rd it rises still more to the north of the east point, and describes a circle still farther north; and so on, till at last on the 21st of June it rises 23½° north of the east point and describes a circle 23½° north of the equinoctial, coinciding with the circle of the heavens named the tropic of Cancer. After this it describes the former daily circles in a reverse order; on 21st September its daily circle is again the equinoctial. On the 22nd September it rises a little south of the equinoctial and describes a circle somewhat to the south of it; each succeeding day it rises still farther to the south of the east point of the horizon and describes a circle crossing the heavens farther south, till at last its daily course is on the circle 23½° south of the equinoctial, called the tropic of Capricorn.

At the poles. To an observer at the poles, the sun, after six months' absence, begins to appear above the horizon, and describes a circle round it—shortly before March 21st at the north pole, and before September 22nd at the south pole. Every 24 hours the circle it describes is higher, till on June 21st or December 21st, according to the hemisphere, it is 23½° above the horizon; after which each day it is lower, till at the end of six months the sun disappears, and remains unseen during the next six months.

At the equator. To an observer at the equator, every day is 12 hours long, and every night the same. The sun passes overhead at midday on March 21st and September 21st; between March and September its daily circle lies to the north of the equinoctial; between September and March it is to the south of it. The sun's course from east to west each day is always exactly a semicircle, perpendicular to the circle of the horizon.

At the tropics. At the tropic of Cancer the sun passes overhead at midday on June 21st, and for the rest of the year its daily circles are south of that tropic. At the tropic of Capricorn it passes overhead on September 21st, and for the rest of the year its circles are north of that position.

In temperate regions.

To an observer between the tropic and the polar circle in either hemisphere, the sun rises in the east and sets in the west parts of the horizon; in the northern hemisphere it is always south at midday; in the southern, always north.

At the polar circles.

At either of the polar circles the longest day is exactly 24 hours, and the longest night the same. From December to June the days increase in the northern, and diminish in the southern hemisphere. From June to December the reverse is the case.

Between the tropics.

To an observer at any place between the tropics, the sun passes overhead at midday at two different periods of the year, with two intervals, during one of which its daily circle will lie north of the zenith, and during the other south of it. The times when the sun passes in, or very near the zenith are the rainy seasons of the different tropical regions; rainy and dry seasons being the only variations which these lands experience.

EXERCISES.

What is the latitude of London, and the height of the equator above the horizon there? If Glasgow be in latitude 55°51′, what is the altitude of the polar star there, and that of the equinoctial at its highest point above the southern horizon? Describe the daily circles of the fixed stars: (a) at the poles, (b) at the equator, (c) in middle latitudes. On what line does the sun describe its daily circle on September 21st, June 21st, March 21st, and December 21st? Describe the positions of the sun's daily circles throughout the year: (a) at the equator, (b) at the tropics, (c) between the tropics and the polar circles, (d) at the polar circles, (e) between the tropics.

VII.

TIME.

Sidereal day. While the earth rotates on its axis from west to east every 24 hours, it is also advancing in its course round the sun. If the sun and a fixed star be on our meridian at the same time on any day, then next day when that fixed star comes again on the meridian by the earth having completed one rotation on its axis from west to east, the sun, having apparently moved eastward among the stars, will be at some distance eastward from the meridian. The earth must therefore rotate a little more than one complete revolution on its axis before the sun comes on to the meridian again. The interval between two occasions of any fixed star crossing the same meridian is called a SIDEREAL DAY.

Solar day. The interval between two transits of the sun across the same meridian is called a SOLAR DAY. Thus it is easy to see that a solar day is always slightly longer than a sidereal day. And since the earth must each solar day turn round eastward, to bring the sun on the meridian, exactly as far beyond the fixed star as the sun appears to have gone eastward among the stars—that is, as far as the earth itself has actually gone on its orbit—when the earth has travelled once round its orbit it will also have to revolve one complete circle beyond the star to bring the sun on its meridian on the day of the completion of its orbit. Hence, when the sun appears to have gone round the heavens in the course of a year, the earth will have made one more revolution before the fixed star which was on the meridian together with the sun at the beginning of this course, than it has made before the sun. While, therefore, there are 365¼ solar days in a tropical year, there are 366¼ sidereal days in it. More exactly expressed, the time in which the sun goes round the heavens from an equinox to the same equinox again is 365 solar days, 5 hours, 48 minutes, 48 seconds; and 366 sidereal days, 5 hours, 48 minutes, 48 seconds.

Irregular apparent motion of the sun in the ecliptic.

But the solar days are not all of the same length. Because of the ellipticity of the earth's orbit the sun appears to move quicker eastward among the stars in winter when it is near the sun, than in summer when it is at the most distant part of its orbit. The earth must, therefore, in order to bring the sun again on the meridian, turn more in excess of a complete revolution, at the one period than at the other. This, of course, causes the solar days to vary in length.

Mean solar day.

The average length of these, or the MEAN SOLAR DAY, is 24 hours; but because of the apparent unequal motion of the sun, it is sometimes on the meridian before, and sometimes later than twelve, by a clock keeping mean solar time.

Sun's path inclined to the equinoctial.

But, again, the path of the sun among the stars is not directly eastward; it is inclined to the equinoctial which crosses the sky directly from west to east, at an angle of 23½°, and is partly above, partly below, the circle of the equinoctial. The sun's daily apparent eastward movement is thus also a slanting movement upward or downward in different parts of its course. At the solstices the sun's path lies very nearly east and west, parallel to the equinoctial, and then his daily progress directly eastward is greater than at other times; thus an irregularity occurs in the intervals by which the earth must exceed a complete revolution, in order to bring the sun once more on the meridian. This becomes another cause of variation in the lengths of the solar days. Had the earth been so set in space that by its annual revolution the sun would have appeared to move on the equator; and had this new sun's path been a circle instead of an ellipse, so that its apparent motion would have been uniform, then mean solar time as shewn by a clock, and actual solar time as shewn by a dial, would both have agreed. But from these two causes: (1) that the earth's path is an ellipse, and (2) that it is inclined to the equinoctial,—a correction of the time of day as shewn by a dial is always necessary in order to find the mean time, or time as used in the affairs of ordinary life.

Equation of time.

This difference between the time shewn by a dial, and that shewn by a correct clock, is called the EQUATION OF TIME; and many almanacks give a column telling this difference for each day, which must be added to, or subtracted from, the time by the clock according as it is before or after the dial. The two times coincide four times a year; not, as one might expect, at the equinoxes, when the sun is on the equinoctial, or at the solstices, when its path is nearly parallel to the equinoctial,—but on 15th April, 15th June, 31st August and 24th December. They differ most in February and November; in February the time by the sun is 14½ minutes behind the clock; in November it is 16 minutes before.

Kinds of days. There are thus three different kinds of days: (1) the sidereal day of uniform duration, measuring the rotation of the earth; (2) the true solar day, of variable duration, marked by successive passages of the sun across the meridian; and (3) the mean solar day—an average of all the different solar days in a year. It is exactly 24 hours in length, and is 3 minutes, 56 seconds longer than a sidereal day.

The Julian Calendar. Since the earth completes its yearly course, not in an even number of days, but in 365¼ days, or somewhat less, it is obvious that this fraction of nearly a quarter of a day must bring the whole day in which it occurs partly into one natural year and partly into another. To prevent confusion from this the CIVIL YEAR is adopted, which usually consists of 365 whole days. And then every fourth year, the four omitted quarter days are allowed to make up a whole day, which is intercalated, or added to the number of days of the fourth year. This fourth year is called leap year, and the month of February gets the additional day. The Romans, who under Julius Cæsar's government adopted this plan and called it the Julian Calendar, made two 24th days of February; and as they named that day the sixth of the Kalends of

March, they called the leap year bissextile, or double-sixth year.

The Gregorian Calendar.

But, as we have learnt, the tropical year is not exactly 6 hours more than 365 days; it is only 5 hours, 48 minutes, 48 seconds more—11 minutes, 12 seconds less than 6 hours. The tropical year is then exceeded by 44 minutes, 48 seconds, after the whole day has been intercalated each leap year; and in the year 1582, this error had increased so that the equinox which should have fallen on the 21st of March, occurred ten days sooner, namely, on March 11. This led to disarrangement of the church festivals, for the dates and the proper seasons did not coincide. By order of Pope Gregory, ten days were struck out of the calendar—those who went to bed on the evening of the 4th October, got up not on the morning of the 5th, but of the 15th October, 1582.

In England the Gregorian calendar was adopted in 1752, by which time the error had amounted to 11 days, so that the next day to September 2nd was called September 14th. In fact, a calendar is simply a mode of naming, or calling, the days of the year; and the object of its arrangements is to secure that, in each different year, days of the same name should occur at exactly the same season. In order to get rid in future of the excess of 11 minutes each yeaı, Pope Gregory enacted that every hundredth year should not be a leap year, with this exception, that every 400th year should be one. Thus all years whose names are divisible by four, as 1876, are leap years. But the last year of any century, though divisible by 4, is not a leap yeaı, unless the two first figures of its name are so divisible. The years

2100, 2200, 2300, will not be bissextile or leap years, but the year 2400 will. Sir John Herschel has proposed that, to correct a small error which would still exist after all these arrangements, every 4000th year should not be a leap year, and then for 28,000 years the Gregorian calendar would work perfectly.

EXERCISES.

What is a sidereal day? A solar day? Why do they differ? How many solar days are in a tropical year? How many sidereal days? What is a mean solar day? From what two causes do the actual solar days differ in length from each other? What is meant by equation of time? When is the equation of time nil? Why might mean and solar time be expected to agree four times a year? Name three different kinds of days? What is the length of a solar day? Of a sidereal day? Of a mean solar day? State the arrangements of the Julian calendar. Of the Gregorian calendar. What makes such arrangements necessary? What is the civil year?

VIII.

THE MOON.

The Moon appears to be nearly of the same size as the sun; and, indeed, there are times when it comes directly between us and the sun and just covers it, or allows only a bright narrow ring of the sun to be seen, as if the moon were but a very little less than it. But, in fact, the moon is not more than one sixty-millionth part of the size of the sun, and is only one forty-ninth of that of the earth. It appears to be as large as the sun because it is only about 240 thousand miles, or 60 times the earth's radius, distant; while the sun is 91 millions of miles away. The diameter of the moon is 2160 miles, or about one-fourth of that of the earth.

Rotation of the Moon.

The moon always turns the same face, or part of its surface, to the earth. This it does because it rotates on its axis and revolves round the earth in the same interval of time. To understand this, carry a watch round a lamp placed on a table, keeping the face of the watch always turned towards the lamp. You will see that the watch is turned round upon itself once during its journey round the lamp. When the watch has been carried half round the lamp, its back will be turned to the opposite wall of the room from that to which it was turned at the beginning of the experiment—that is, it has been turned half round; and when the circle round the lamp has been completed, the back of the watch will again be turned to the same wall as at first—it has been turned wholly round on its axis.

Sidereal month.

As the earth revolves round the sun, so the moon revolves round the earth. It completes this course in 27 days, 7 hours, 43 minutes; or rather it completes a circle among the stars in that time. Each night it may be observed among stars much farther to the east than those it was among the previous evening, till at last it returns to those amongst which it was when its motions were first observed. It has thus fulfilled what is called a SIDEREAL MONTH, in the same way as the sun fulfils a sidereal year.

Phases.

During this course among the stars, the moon assumes different shapes, or phases;

as they are called—crescent, semi-circular, full, then again semi-circular, and finally for a time disappearing. When it appears as a thin crescent, or rather immediately before, while still invisible, it is called new moon; when as a full round orb, it is full moon. From full moon to full moon, or indeed from any one phase to the recurrence of the same again, is 29 dys., 12 hrs., 44 mins., 3 secs., called a SYNODICAL MONTH. The cause of the difference between a sidereal and a synodical month will be easily understood when we have studied the cause of the phases.

Varying positions of Moon and Earth.

Since the moon goes round the earth while the earth goes round the sun, it is easy to see that it must sometimes be between the earth and the sun, and sometimes on the side of the earth turned away from the sun. When the moon is between the earth and the sun, both moon and sun are seen on the same side of the sky, and are said to be in CONJUNCTION; when the moon and sun are on opposite sides of the earth, they are said to be in OPPOSITION.

Cause of the Phases.

Now, the moon has no light in itself; we see it only by the light of the sun which it reflects. Its light side is, of course, always that side which faces the sun. When, therefore, it is between the earth and the sun its dark side is turned towards us on the earth; and though it is somewhere in the western sky near the sun at sunset, we see nothing of it. But, as it edges off eastward from between the earth and the sun, a part of its bright side is seen as a thin crescent with horns to the east. Night after night this crescent waxes or becomes larger; till about a week after its first appearance it is seen as a half moon in the south, when the sun is setting; for at that time, one half of the side which is turned to the earth is bright because it is turned towards the sun, the other half is dark because it is turned from the sun. The moon has now gone a fourth part of the circle of the heavens eastward from between the sun and the earth. When it has gone eastward half round the heavens, and is now directly opposite to the sun, the whole of its bright side is turned to the earth as well as to the sun. It then rises in the east as a round full moon, when the sun is setting in the west.

Waning Moon. After the period of full moon it continues its course eastward till it comes once more to conjunction with the sun, and during that part of its course less and less of the side turned to the sun coincides with the side turned to the earth. It is then what we call the waning, or lessening moon; from full, it becomes half moon, and after this a thin crescent with its horns turned westward or from the sun, and may often be seen during the day a little to the west of the sun. Finally it approaches the sun, falls into conjunction with it, and then the side lightened by the sun is turned wholly away from the earth; the moon therefore disappears from our view till it has again passed the sun.

Earth-shine. The times of conjunction and opposition, or new and full moon, are called the SYZIGIES; the times of half moon, waxing or waning, are called the QUADRATURES. A day or two after new moon, while only a thin crescent is bright, the rest of the moon's circle may be seen dimly by light which the earth reflects to that part of the moon, and which is reflected back again to the earth.

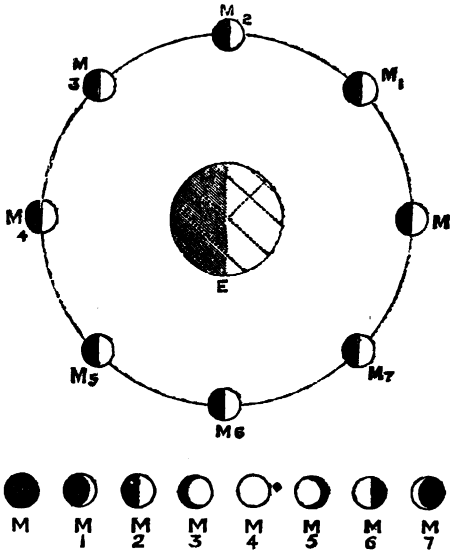

Fig 11.

Phases of the Moon.

The sun is supposed to be on the right, at a distance of 380 times the length from E, the earth, to M, the moon.

M, new moon. M4 full moon. M^2, M6, quadratures.

M1, M3 M5, M7, octants.

M, M1, . . . M7, appearance of the moon, in the successive positions of its orbit.

Synodical month. From full moon to full moon, —that is, a synodical month—is longer than a sidereal month, because while the moon is making its course round the stars in a month of 29½ days, the sun has also been making about a twelfth part of its course round the ecliptic during that time. Hence, the moon, starting at new moon from between us and the sun, to go eastward among the stars, is followed slowly by the sun in the same direction, as the long hand of a watch is followed slowly by the short one. When, therefore, the moon has gone completely round the heavens, and at the end of a sidereal month returns to the point from which it had last set out as new moon, the sun is no longer there, it having gone on eastward about 30°, and the moon must consequently go on its next course something more than 30° before it can come again between us and the sun, and thus complete the synodical month. So the hands of the clock which are together at 12 o'clock are not together again when the long hand has completed its round; for the short one has travelled slowly in the same direction $\frac{1}{12}$th of its round, and therefore the long one must go above $\frac{1}{12}$th of its next round before they come together again, after one o'clock.

Libration. It is not literally the case that we on the earth can see nothing more than one half of the moon. Its axis is inclined about 6½° to the plane of its orbit round the earth; that is, to the plane in which we as observers of the moon are placed; and sometimes, therefore, we see so far as 6½° beyond its poles on either end of its axis, just as an observer from the sun would see beyond the south pole of the earth in December, and beyond the north pole in June. Sometimes, too, we gain glimpses of the moon sideways, owing to its not turning on its axis uniformly at the same rate as it advances in its orbit round the earth. The first variation of its position in regard to us is called LIBRATION in latitude; the second, LIBRATION in longitude.

Moon's surface. Since the moon turns on its axis only once in 27¼ days, its day and night are each nearly 14 of our days and nights in length. There is no atmosphere in the moon; it has no clouds; there can, therefore, be no water in it. Its day side will be scorched and glaring; its night side frozen and black, for where there is no air there can be no twilight. The moon, seen through a telescope magnifying 1000 times, presents the same appearance as though viewed by the naked eye at a distance of 240 miles. Its surface is diversified with mountains, hills, and valleys. These are dry and barren, for where there is no water, plants cannot grow. On the moon silence still as death must prevail, for where there is no air, no sound can be heard.

Lunar day. A lunar day, like a solar day, is longer than a sidereal day, and for the same reason. The moon, as we have seen, advances about 12° eastward among the stars daily, and therefore the earth must revolve from west to east 12° more than a complete sidereal revolution, in order to bring the same meridian once more under the moon. The mean, or average, lunar day is thus 24 hours, 50 minutes long.

Lunar orbit. The orbit in which the moon moves round the earth is not, so to speak, on the same level in space as that in which the earth moves round the sun; but is inclined to it 5°. It is, therefore, a circle in the heavens 5° above the circle of the ecliptic at one part, and as many degrees below it at the opposite part; but crossing the ecliptic and, of course, coinciding with it at two opposite points of the sky, called the NODES. It is clear, therefore, that however high above the horizon the sun in its path may ever be, the moon may be at times 5° higher; and however low the sun may at any time be, the moon may be at times 5° lower.

Eclipses, Total and Annular.

The shadow of the earth extends through space on the side opposite to that on which the sun shines; and sometimes, the full moon, being of course in opposition, passes along its orbit through this shadow, and becomes darkened, or eclipsed. Again, at new moon, when the moon and sun are of course on the same side of us, the moon sometimes comes directly between us and the sun, and hides or eclipses it. The moon's dark round body is then seen against the bright sun; and if the moon happens to be in that part of its orbit which is nearest, when it appears to us to be somewhat larger than the sun, it at such times completely hides the sun and causes what is called a TOTAL eclipse. If during an eclipse of the sun, the moon happen to be at the most distant part of its orbit from us, it appears somewhat less in size than the sun; and at the central moment of the eclipse the moon forms a black circle on the face of the sun, and is surrounded by the bright edge of the sun, as by a ring. This is called an ANNULAR eclipse.

They occur only at, or near, the nodes.

Why, it may be asked, does not an eclipse of the sun happen at every time of new moon, and an eclipse of the moon at every time of full moon? If the moon's orbit had been on the same level or plane with that of the earth, an eclipse would certainly have happened at every time of conjunction and opposition. But in going round the earth the moon may come on to the same side of the earth with the sun, and yet not be on a level with it, for as we have seen it may be in a part of its orbit higher or lower than the sun's place in the ecliptic. Only at, or near, the nodes or crossings of the two orbits can the sun and moon approach the same level to our eyes; and if, when the moon is in conjunction or opposition, it be not at or near one of its nodes, but in a part of its orbit above or below them, then as new moon it will pass the sun without eclipsing it, because it passes either too high or too low. This is why the level or plane of the earth's orbit is called the ecliptic, because the moon must be in a part of its orbit which is nearly level with it ere eclipses can occur. Unless a new moon is within 17° of a node, or a full moon within 11° 21′ of one, there will be no eclipse; therefore, the moon moving within a space of 34° may eclipse the sun; while only within a space of 22¾° can the moon itself be eclipsed by the earth's shadow. For this reason eclipses of the sun occur oftener than eclipses of the moon.

Number of Eclipses in a year.

Every 18 years eclipses succeed each other very nearly in the same order. In that time there may be altogether 70 eclipses, 29 of the moon and 41 of the sun. In any one year there can never be more than 7, or less than 2; and if there be only 2, they will both be eclipses of the sun. The number of eclipses that can be seen from any one place is fewer of the sun than of the moon; but, taking the earth as a whole, the number that can be seen from one place or other is greater of the sun than of the moon.

Eclipses of Sun not visible everywhere.

The reason why from any one place more eclipses of the moon than of the sun can be seen—is that an eclipse of the moon is visible wherever the moon is visible, but the sun may be eclipsed at one place above which it is shining, and yet not at another. A shadow on a surface is, of course, a shadow to all who can see the surface; the shadow of a chair on a wall, for instance, can be seen from any part of a room. But a dark object which hides a bright one from one person in a room, may not hide it from another, or from the same person, in a different part of the room. A screen may hide the fire from me in one corner, while from another I may see between the screen and the fire. So the new moon may hide the sun from some of the people in Europe, and not from those in Asia or America.

Partial Eclipses.

Eclipses may occur in which the moon is only partly in the earth's shadow; or in which only part of the sun is hidden by the moon. These are called partial eclipses. The central part of the earth's shadow, called the UMBRA, is deep and black, because the earth cuts off all the sun's rays from that part. Towards the edges, light mingles with the shade, forming what is called the PENUMBRA. In the shadow of a stick thrown on a wall by the light of two candles we can see a deep central umbra, with a faint penumbra on each side. The moon's passing only through the penumbra is not reckoned as an eclipse.

Law of Gravitation.

The same force of gravity by which the earth draws objects above its surface towards it, is exerted by the sun and moon on every particle of the earth and the waters which flow over its surface. Every particle of matter, in fact, has a force of attraction, or pulling, which it exerts upon every other particle in the universe. This force increases as the mass of the attracting body increases, and diminishes as the distance multiplied by itself—that is, the square of the distance—increases. This truth is called the Law of Gravitation, and is generally expressed by the statement that all bodies attract each other directly as their masses and inversely as the squares of their distances. The sun and the moon, therefore, attract the earth and the waters on the earth according to this law.

The Tides.

The tides consist in a rise and fall of the waters of the ocean twice daily; the rise being called FLOOD; and the fall, EBB. This rise and fall occurs on every shore, but earlier on any given day the farther east a place lies; and shortly after new and full moon the risings are higher and the ebbs lower than at other times. The highest tides are called SPRING TIDES. The cause of the rise of the waters is that the attraction of the sun and moon is greater on the waters of the surface nearest them than it is on the centre of the earth. These waters therefore rise up from the centre. But their attraction is also greater on the centre of the earth than it is on the surface farther off; therefore, the central parts and solid ~~mass of the earth~~ rise as it were towards the sun and moon, and leave behind the waters at the distant surface. Thus on both sides of the earth, at opposite parts of the diameter along which the attraction of the sun and moon is acting, there is a movement of the waters away from the centre.

Difference of Attraction at Centre and Surface.

There are, therefore, two tides at once, on opposite sides of the earth, caused, let us notice, by the difference of the attraction of the sun and the moon on the centre, and on the near and far surfaces of the earth. The difference in the case of the moon is about $\frac{1}{30}$th of its whole attraction; in the case of the sun it is only about $\frac{1}{12000}$th of its whole force. The result is, that the moon, though it has but $\frac{1}{195}$th part of the force of attraction that the sun has, yet has much more effect in causing the tides. For $\frac{1}{195} \times \frac{1}{30}$, or $\frac{1}{5850}$, is more than twice $\frac{1}{12000}$, and therefore the moon has more than twice the influence in producing the *difference* which causes the tides.

Time of Tide differs at different places.

The fact that the tides occur earlier to places the farther east they lie is explained by the earth's rotation from west to east; they therefore follow the sun and moon in their apparent daily course from east to west.

Difference of times of tide at the same place.

But at the same place, on any day, the tide rises about 50 minutes later than it did on the day before. The reason is that the moon, which is the chief agent in causing the tides, moves about 13° eastward daily in its course round the stars; and the earth, in revolving from west to east, must, therefore, move somewhat more than a complete revolution before any one place—or rather the places on any one meridian, having had the moon in that meridian—can be brought round so that it shall be there once more. The case is similar to that of the long hand of a clock, which, starting from being alongside the short one at twelve o'clock, must go once round, and somewhat more, before it again lies alongside of the short hand at about 5½ minutes past one o'clock. For the short hand, too, moves round on the clock face; as the moon does among the stars, while the earth revolves.

Spring Tides. The spring tides occur at full and at new moon, because then the attraction of the sun and the moon being in one line, the waters are raised by both together; the tides on the near and far sides of the earth caused by the moon, coinciding in both cases with those on both sides caused by the sun. The highest spring tides occur when the sun and moon in opposition or conjunction happen also to be, each of them, at their points of least distance from the earth—the sun in perihelion, the moon in perigee.

Priming and lagging. When the sun and moon are not in the same straight line, then they each exert an influence on waters at different points on the earth's surface, and cause low or NEAP TIDES. Sometimes the separate influence of the sun hastens, sometimes it hinders the rising of the lunar tides. This is called the PRIMING and the LAGGING of the tides.

Establishment of a Port.

The settlement at any port of the time between new or full moon, and that at which the spring tides occur at that port, with the calculation of the monthly series of tides that follow this, is called the ESTABLISHMENT of the port.

Tide Wave.

Were the earth a globe covered with water, then the tides would form a great wave, rushing round it after the sun and moon, within a belt of 28½° north and south of the equator. The masses of land and their projections prevent any such uniform rise and movement of the tide wave. The expanse of water amid which it has most scope to rise is that of the South Pacific Ocean between Cape Horn and Australia. Here the tide wave may be considered to begin to move; and from this to press forward northward and westward after the moon, hindered in its progress by shoals and islands and headlands. The tides in small seas are raised not directly by the influence of the sun and moon, but by the rushing of the waters of the great wave into them. From the South Pacific this wave passes round Australia on the north and south, enters the Indian Ocean, winds round the Cape of Good Hope, and rushes northward through the Atlantic into the Arctic Sea. It would have gone round the world in 24 hours had there been one continuous sea; but, as things are, it requires 12 hours from Tasmania to Cape Comorin, and 12 hours more to pass up the Atlantic as far as Cape Blanco on the one side, and Newfoundland on the other. Part of it, turned by the peninsula of Scandinavia, flows southward through the German Ocean and is off Aberdeen in other 12 hours; and, in yet other 12, being now 48 hours from Tasmania, it is off the mouth of the Thames, and meets there with a part of the next tide wave, only 36 hours old, which has taken a shorter route from the Atlantic by coming up the English Channel. Lines on a map connecting all places that have high water at the same time are called COTIDAL LINES.

Tidal Bore. In narrow straits and up rivers, the front of the tide wave forms a high mass of waters called a TIDAL BORE. In the Amazon the bore is sometimes 180 feet high. In the open sea the average rise of the tide is 4 or 5 feet; in the Bay of Fundy, where the waters are hemmed in, the tide rises sometimes 120 feet; at St. Malo, on the coast of France, it rises 50 feet.

Harvest Moon. The moon, as we have learnt, moves in an orbit which is inclined 5° to the ecliptic, and is therefore at times 28½° north of the equinoctial, at others 28½° south of it. The equinoctial, being always 90° from the pole, is always, like the pole, at the same height above the horizon. One half of the moon's orbit, then, is steep to the horizon when above it; the other is much less above, or more level with it. Let us suppose that the moon moves along the equinoctial from west to east among the stars, at its ordinary rate of about 13° daily. Its whole course from the spring to the autumnal equinoctial point would be north of the equinoctial; and from the moment of its crossing the spring equinoctial point on its route eastward it would at the same time advance northwards for a quarter of its circle. Inasmuch as it moves daily about 13°, its times of rising would be on the average 52 minutes later each day. But about the time when it is in the spring equinoctial point, its advance northward on its course prevents its falling so much below the horizon of northern countries as it would have done had it moved directly eastward through the heavens. Hence, when it is at this part of its orbit, it appears above the horizon of such countries at nearly the same hour for a number of evenings in succession. This happens every lunation, or month. But when the sun is in the autumnal equinox, the moon in the spring equinoctial point is directly in opposition, and is a full moon. The full moon, therefore, in September rises at the same hour for some evenings in succession; at the hour, too, when the sun sets. What is thus true when explained of the moon as if it moved on a circle inclined 23½° to the equinoctial, is equally true of it moving, as it really does, in a circle inclined 28½° to it; for its advance northward, as it progresses on its orbit at the time of the equinox, is even more marked than it would be on the ecliptic. The September full moon is of special advantage to the reapers, and is called the HARVEST MOON.

EXERCISES.

What is the distance of the moon from the earth? What is the length of its diameter? Why does it always turn the same face to the earth? Describe the course of the moon among the stars in a month.

Describe its phases. What are the lengths of a sidereal and a synodical month? What is meant by conjunction, and by opposition of the moon? What are the Quadratures? What amount of the moon's circle is bright at each of these positions? In what direction do the horns of the new moon point? In what direction do those of the waning moon point? If the moon be seen in the daytime west of the sun, how do its horns point? and is it waxing or waning? What are the syzigies? What causes the difference between a synodical and a sidereal month? What is libration, (a) in latitude? (b) in longitude? What is the length of a day and of a night at the moon? Why is a lunar day about 50 minutes longer than a solar day? Why may the moon sometimes be higher above the horizon than the sun can ever be?

What causes an eclipse of the moon? Of the sun? What number of eclipses may occur in a year? What number must occur? Why do not eclipses happen at every new and full moon? Why are there more eclipses of the sun than of the moon? and why are more eclipses of the moon seen at any one place? Under what circumstances do total, annular, and partial eclipses of the sun occur? What is meant by attraction of gravitation? At what rate does its force increase and diminish?

What are the tides? How many tides occur on the earth at one time? What is the cause of each of the tides which rise at the same time on opposite parts of the earth? Whether has the sun or the moon most influence on the tides? Why has one more than the other? Why do the tides usually occur earlier to a place east, than to one west of a given meridian? What are the priming and lagging of the tides? What is the establishment of a port? Describe the course of the tide wave. In what does the harvest moon differ from the moon at other seasons? What causes its unusual appearance?

IX.

DISTANCE OF SUN, MOON, AND STARS.

Parallax. As we move from place to place any object at a distance from us seems to change its position in reference to the objects behind it, such as the trees of a wood, or the parts of a wall against which it happens to be seen. If the object be very near the course along which we move, its apparent change is considerable. Before starting we may have seen it exactly to the left, and may find at the end of our course that it is a good way behind us on the left. This apparent angular change in the position of an object, owing to our real change of place, is called the PARALLAX of the object; so that parallax may be defined as the difference of the angles under which an object is seen from two different positions. This difference is greater the nearer the object is to the line joining the two positions, and the amount of it may be determined by the distance between the parts of the background against which the object is seen in the different positions. If there be no apparent change in the position of the object, that is, if it have no parallax after we have moved a long way, then we may be sure that the object is at a great distance. Even in the dark we may judge of parallax and distances. Thus, if we see a fire at some unknown distance to the north of us, and if, after we have gone a good way east or west, it still seems to be north of us, then, since its parallax, or apparent change of direction, is small, its distance is great.

Estimation of Distance of Objects.

If, for example, a person walk round a circle 40 yards in diameter, and a point in a wall, or a wood, exactly behind a post in the distance be noted as he starts, he will, as he moves, see the point and the post separating from each other, that is, increasing their angular distance from his view-point according as he varies that view-point in going round the circle. Such variations of the line of direction in which the post and the point is seen, he will be able to observe even if the post be at as great a distance as 100,000 times the diameter of the circle round which he walks. Beyond this distance, however, he may go round the whole circle and yet will see no apparent change in the relative positions of the post and the point in the background.

Distance of the Fixed Stars.

It is by a similar mode of trial that we judge of the immense distance of the fixed stars. We, on the earth, move annually round the sun in a circle which has a diameter of twice 91 millions, or 182 millions of miles; and yet those stars, with some exceptions, shew no change in their relative positions,—they have no parallax. This proves that the distance of the fixed stars from the earth must be at least 100,000 times 182 millions, or above 18 billions of miles.

Use of Parallax.

The greater the parallax of an object, the nearer that object is. In finding the distance of a heavenly body, the first thing to be done is to find its parallax, or the angular difference of the directions it has when seen from two different positions on the earth. This difference is also the angle under which, if we were at the body, we should see these different positions; or as mathematicians express it, the angle subtended at the heavenly body by the line joining the two positions on the earth. Having found that angle and measured the distance between the two positions, then from what mathematicians have taught respecting angles and the triangles of which they form a part, we can easily find the distance of the sun, moon, or any planet.

Horizontal Parallax.

Thus, the radius of the earth, which has a known length, is assumed as the line joining two positions of observation, of which the end of the radius at the surface is one, while the centre of the earth is the other; and then by an ingenious series of measurements, the angle is found under which that radius would be seen at the distant sun, moon, or planet. This angle, subtended by the earth's radius, is called the HORIZONTAL PARALLAX, because it is found by observations made when the sun, moon, or planet is on the horizon of one of the places of observation. If the radius of the earth is found to subtend an angle of 1° at the distant object, then that object must be, by the laws which apply to the sides and angles of triangles, at a distance from the earth of 57.38 times the earth's radius; if it subtends an angle of 1′, it is 60 times more distant, or 3,442 times the length of the earth's radius off; and if it subtends an angle of 1″, it is at a distance of 206,000 times the radius of the earth.

Distances of Sun and Moon.

The distance of the moon has thus been found to be rather more than 60 times the earth's radius, or more exactly, 238,851 miles. At the point where it is nearest the earth, called the PERIGEE, its distance is 226,000; and when it is farthest from the earth, in the point called APOGEE, it is about 252,000 miles distant. In a similar way, the sun's distance is estimated to be above 91 millions of miles; and, as we have already seen, it is above 3,000,000 of miles nearer the earth at its nearest point of approach, or PERIHELION, than it is at its greatest distance from the earth, or APHELION.

Light of distant Stars.

With a few exceptions, the fixed stars have no observable parallax. Those which have, must be at a distance almost inconceivable, so small is its measure. From the nearest star, whose distance has been estimated by its parallax, light, which travels 186,000 miles in a second, would require about 3½ years to arrive at the earth. From another star, whose distance has been thus calculated, the light reaches us after a journey of 10 years; so that it is conceivable, that in these stars some living being is now gazing upon the earth, and seeing, by the light which left it respectively 3 and 10 years ago, what happened on the earth at these times, as if it were happening at this moment. Of worlds that have long ceased to exist, we may be now receiving information by light that left them centuries ago; just as one may receive by post, and read a letter from a friend, who, when it comes to hand, has been weeks in his grave.

To find the distance of the Moon.

With the help of figure 12 we may be led to understand more fully the manner in which the distance of the moon from the earth is found. Let the inner circle represent a meridian on the earth; the outer one, a meridian in the heavens; A and B, the situation of two observers on the same meridian 100° apart; A say at Tornea in Finland, and B at the Cape of Good Hope; *Z*, *Z'*, the zeniths of those places; and the straight line AB, a cord of the arc joining them. The two observers, at a time previously agreed upon, mark the place among the stars in which each from his own standpoint sees the moon, M. B sees it against the fixed star *c*, and A against the fixed star *d*. Then the arc from *Z* to *d* is the moon's zenith distance at A, which is the same in degrees as the angle *ZAM*; and the arc from *Z'* to *c*, or the angle *Z'*BM, is the zenith distance at B. The angle at the

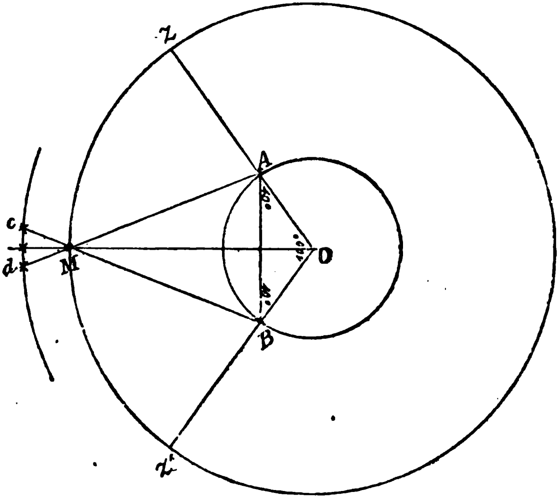

Fig 12.
Distance of the Moon.

O, centre of the Earth.
AB, a terrestrial Meridian.
ZMZ'', a celestial Meridian.
M, the Moon.
***c*,*d*, stars behind the Moon's apparent positions.**
A.B, positions of different observers.
Z,Z', Zeniths of the observers at A and B.

centre of the earth, O, is the same in degrees as the degrees of latitude between A and B, namely 100°. Since the two radii of the earth, OA and OB, are equal (each being about 4,000 miles), the angles OAB and OBA are equal, and in this case each of them is 40°; for 100° taken from 180°, (the amount of the three angles of the triangle OAB) leaves 80° to be divided equally between OAB and OBA. The length of the cord AB is then easily calculated. Then in the triangle AMB we know the angle MAB, for it is 40° + ZAM, (the zenith distance of the moon at A) subtracted from 180°, which is the sum of all the possible angles at the point A, on the same side of the straight line OZ. We know, too, the angle MBA, for it is 40° + ZBM, (the zenith distance at B) subtracted from 180°; and we know the side AB. That is, we know, two angles and one side. Then, by the rules for triangles, the lengths of the sides AM and BM, are easily found; and these are the distances of the moon from A and B respectively. Knowing now AM, and AO, the earth's radius, and the angle MAO between them (it is 180°—the moon's zenith distance at A), that is, two sides and the angle they contain, the line MO which is the distance of the moon from the earth's centre can be easily found

Transit of Venus. The distance of the sun from the earth is found by observing the planet Venus when it comes directly between the earth and the sun, and moves across the face of the sun, eclipsing it, as a very small moon would do. This is called the transit of Venus. Two transits, eight years between them, occur in a period of rather more than a century. The finding of the sun's distance is a much more complicated process than that of finding the moon's. Two observers on the earth, as far apart as possible, watch the transit. The one to the south will see Venus on a higher part of the sun's disc than the one to the north; as in the case of the moon (see figure 12), while the one sees it at *c*, the other sees it at *d*.

If two men at two positions widely apart look at a post standing between them and a wall, they will each see the post against different parts of the wall. If the post be the same distance from the wall as from the men, the distance of the parts of the wall hidden from each man by the post will be the same as the distance of the men from each other. If the wall be twice as far behind the post as the men are in front of it, then the distance betwen the hidden spots will be twice the distance between the men, and so on.

The sun is 2½ times farther from Venus than the earth is; therefore, in the same way, the actual distance between the parts of the sun eclipsed by Venus, to the two observers at the same moment, will be 2½ times their actual distance from each other. Suppose them to be one at each end of the earth's polar diameter, that is, about 7,200 miles apart, then the actual distance on the face of the sun between the two points which, ***at the same moment***, appear hidden to the observers, will be 2½ times 7,200, or 18,000, miles. It is easy now to find what part of the sun's whole diameter this is, and thus the actual length of the sun's diameter becomes known. Now the angle which the sun's diameter subtends at the earth is nearly 32′, and whatever subtends this angle must be at a distance of about 108 times its own length. Having first found the actual diameter, which is about 850,000 miles, the actual distance is this multiplied by 108.

The angular distance between the points of the sun against which the planet appears to these two different observers at any given moment will be 2½ times the angle at which the earth's diameter would be seen from the sun, or 5 times the angle at which the earth's radius would be seen; that is to say, 5 times the sun's horizontal parallax. But though the space included by this angle on the face of the sun may be easily seen, it is not easily measured, its extremes being points on a bright disc. The plan adopted is, for each observer to carefully note the beginning of the petty eclipse or transit, that is, the moment of contact; also the line which the planet takes across the sun, and the moment at which it leaves the disc, that is, the moment of egress. They thus get the exact times occupied by the transit at the respective stations; and

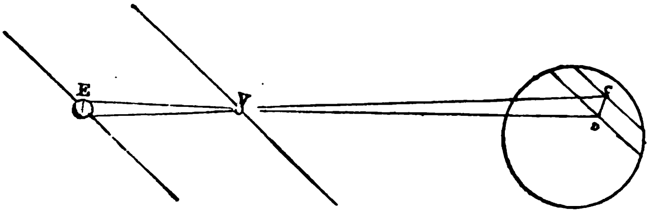

Fig. 13.
Transit of Venus.
E, the earth. V. Venus. C, the point of the Sun's surface on which Venus is seen by one observer, when she appears to another on the point D. CD, breadth of the zone between her apparent paths across the sun.

the difference of these times shews the difference of the lengths of the lines it has appeared to traverse. It is easy then to find exactly the parts of the sun's disc which the lines cross, and to calculate the breadth of the zone between them. This breadth will be 2¼ times the diameter of the earth.

EXERCISES.

What is parallax? How may its amount be judged of? How does it prove the immense distance of the fixed stars? How may the parallax of a distant object be expressed, considered as viewed from the object? What is horizontal parallax? If an object of known length subtend an angle of 1°, how many times its own length must it be distant? If it subtend an angle of 1′, how far off must it be? What is meant by perigee and apogee? Illustrate by the velocity of light the distance of some of the fixed stars. Describe the method of finding the distance of the moon. Give an outline of the mode of finding the distance of the sun by observing the transit of Venus.

X.

THE SOLAR SYSTEM.

The Planets. The earth, attended by its satellite the moon, as we have seen, revolves round the sun in a year, in an elliptical orbit. It also rotates once in 24 hours, on an axis inclined to the plane of its path round the sun, and this axis points always in the same direction in space, through whatever portion of its orbit the earth may be moving. Other bodies, called planets, of the same nature as the earth, revolve round the sun; some nearer to it than the earth is, some farther off. These planets have axes of rotation inclined to the planes of their paths; and they change their places in our sky, while advancing on their paths, being sometimes of the same side of the sun as the earth is, and sometimes on the opposite side—that is, in conjunction or in opposition. Those which revolve in an orbit nearer the sun than the earth's orbit are called INFERIOR PLANETS; and sometimes, when they come between us and the sun in the nodes or crossings of their orbits and the earth's, they appear on the face of the sun, crossing it, and causing a miniature eclipse, as we have already seen in the case of Venus. Those which move in orbits farther from the sun than the orbit of the earth are called SUPERIOR planets. Since all the other planets move around the sun at different rates of velocity from that of the earth, they appear to us sometimes to go before the sun in its daily course, sometimes to fall behind it, sometimes to stand still altogether, and sometimes to rush rapidly forward. The facts that these other planets do move round the sun, and that they do rotate on their axes, and are round, mostly somewhat flattened at their poles, form a strong argument for the likelihood that the same facts in regard to movement and shape are true respecting the earth.

Bode's Law. The names of the planets in their order of distance from the sun are: Mercury, Venus, the Earth, Mars, the Asteroids, (a group of about 150 small planets) Jupiter, Saturn, Uranus, and Neptune. Mercury is 35 millions of miles distant from the sun; Venus, 66 millions; the Earth, 91 millions; Mars, 139 millions; the Asteroids vary; Jupiter is 476 millions; Saturn, 872 millions; Uranus, 1,753 millions; and Neptune, 2,746 millions. There is a law or rule, called BODE'S LAW, by which the distances of the planets were once considered to be regulated. According to it, the intervals between the orbit of Mercury and the other orbits go on doubling as they go farther from the sun. Thus, the Earth is about twice as far beyond Mercury as Venus is; Mars, 4 times; the Asteroids, on the average, 8 times; Jupiter, 16 times; Saturn, 32 times; Uranus, 64 times. This law is, however, completely falsified by the orbit of Neptune, which is not nearly double the orbit between Mercury and Uranus.

Relative Distances and Magnitudes.

If a globe of two feet in diameter were taken to represent the bulk of the sun, a mustard seed, 164 feet off, would serve for Mercury; a pea, 284 feet off, would serve to represent Venus; another pea, 430 feet off, would serve as the Earth; a few grains of sand, lying about 1,000 feet off, would represent the Asteroids; an orange, half a mile away, would stand for Jupiter; and another orange, four-fifths of a mile off, for Saturn; a cherry, a mile and a half off, would be Uranus; and a plum, two miles and a half from the globe, would represent Neptune.

Their Years.

These distances would, of course, represent the radii of the different circles round which the different objects should be carried to represent the orbits of the planets; the times of their completing the circles, that is, the years of the different planets increase with their distances. The year of Mercury is 88 days long; that of Venus, 224 days; the Earth's, 365¼; that of Saturn, above 10,000; of Uranus, above 30,000; of Neptune, above 60,000. So that, if there were inhabitants of Neptune with their lifetime reckoned by the number of *their* years, and developing in one such year not more than man does in a year, the children who were born there in the year *one* of our era are still at school; those born there when Joseph was in Egypt are now rising young men and women; and threescore and ten years there are as ten thousand here.

Their Days.

The days of the planets, or the times of rotation on their axis, are as various in length as their years. The days of Mercury, Venus, and Mars do not differ much from our own day of 24 hours; Jupiter's day lasts only 9 hours 56 minutes; Saturn's, 10¼ hours; and the sun itself rotates on its axis in 25 days 10 hours, as can be seen by the movement of the spots on it. The earth, as we know, has one satellite, and Jupiter has four. Saturn, too, has eight; Uranus, four; and Neptune, one. All the planets revolve round the sun from west to east, and rotate on their axes in the same direction. Their satellites, too, rotate from west to east, except those of Uranus, which rotate from east to west.

Laws of Kepler.

Regarding the movements of the planets round the sun, Kepler, the famous astronomer, found out three general facts which are often spoken of as Kepler's Laws:—

(1.) That the planets all move in ellipses, of which the sun occupies one of the foci.

(2.) That the motion is more rapid the nearer the planet is to the sun; so that the RADIUS VECTOR—that is, a line joining the planet to the sun, stretching and shortening as the sun and the planet are distant or near—sweeps over equal areas of space in equal times.

(3.) That the squares of the times of revolution of the planets are in the same proportion to each other as the cubes of their distances.

Comets. Besides the planets there are other bodies which revolve round the sun. Among them are comets. They are strange tailed stars, varying in size and brightness, dim for the most part, with a bright central part called the nucleus. These come only at times as visitors of the regions within our ken from a long distance, pass round close to the sun, increasing in brightness as they approach it, and then fly off again to unknown immensely distant parts of space; some to remain away for ever, some to return in a few years. The planets in their courses keep near the ecliptic, while comets move through curves in every plane; all the planets move round the sun in the same direction as the earth, some of the comets move in a contrary direction.

Meteors. Among the other bodies in relation with our sun are METEORS, which almost any night, and especially in August and November, may be seen flashing out of the darkness for a moment; and which when they fall to the earth, form the stones called METEORITES. They are small dark bodies, and revolve in immense numbers round the sun. They become bright only when they are drawn by the earth's attraction, and begin to burn in falling through the air.

For the most part they are consumed before they reach the ground; a few only are spared to stimulate the curiosity of philosophers, and to grace museums. The orbits of these meteorites are found to be the same as those of some of the comets; and hence it has been suggested, of late years, that comets are clusters of meteorites keeping together in space, as they fly in their orbits round the sun.

The Solar System. The sun, the moon, the planets, comets and meteoric bodies are all included in what is known as the solar system. These planets, satellites, and comets derive their light from the sun, and shine on us by reflecting it; while the fixed stars shine by their own light. The fixed stars are themselves suns, probably with worlds revolving round them and dependent on them for heat and light, but too distant for our telescopes to track. The probability is, that no two of the fixed stars are nearer each other than the nearest of them is to our sun.

EXERCISES.

In what respects do the planets resemble the earth? What are superior planets? Inferior planets? Give the names of the planets in their order of distance from the sun. What is Bode's Law? Illustrate the relative distances and magnitudes of the planets by the sizes and positions of common objects. Illustrate by comparison with the lives of human beings the lengths of the years of some of the planets. What are Kepler's three laws? What is meant by radius vector? What other bodies besides the planets revolve round the sun? What group of objects forms the solar system?

XI.

GRAVITATION.

Kepler's Facts. The three facts observed by Kepler are commonly called Kepler's laws; but they are not laws in the proper acceptation of the term. They were simply unconnected facts, whereas a law means a truth which binds a number of facts under one statement—a truth of which all these facts and others that may be predicted are consequences.

Newton's Law. Sir Isaac Newton discovered the law of which Kepler's facts are consequences—namely, the Law of Gravitation. From the fact, that the areas described by the radius vector are proportional to the times of revolution of the planets, Newton shewed that the planets must be acted on by a force proceeding from the sun; from the fact, that they move in ellipses of which the sun stands in one of the foci, he shewed that this force increases as the square of the distance from the sun decreases; and from the fact, that the squares of their times are to each other as the cubes of their distances, he shewed that the force is proportionate to the mass. These three conclusions led ultimately to the LAW OF GRAVITATION, namely, that "every particle of matter attracts every other, and that the attraction is in direct proportion to the mass and inverse proportion to the distance of the attracting bodies." With this force of attraction from the sun acting upon the planets, and driving them through space, with an original force and so keeping them from falling to the sun, Newton accounted mechanically for the wondrous arrangement by which they all keep their apppointed courses.

Attraction at the Earth's Surface.

By the force of attraction the earth draws bodies to it, so that at its surface—that is, at the distance of its radius from the centre—they fall 16½ feet in one second of time; 3 × 16½ in two; 5 × 16½ in three; 7 × 16½ in four, and so on, the more rapidly the longer the time of falling. In two seconds therefore a body will have fallen altogether 4 × 16½ feet; in three, 9 × 16½; in four, 16 × 16½, and so on; that is, the distance through which a body falls in a given time may be found by multiplying 16½ feet by the square of the number of seconds in that time.

Attraction at the Moon.

Since we know the amount of the earth's attraction at the surface, or the distance of one radius from the centre, it is easy to calculate what must be its force at the moon, at the distance of 60 radii. It must be as much less as the square of the distance is greater, and will therefore be not $\frac{1}{60}$th, but $\frac{1}{60} \times \frac{1}{60}$th, or $\frac{1}{3600}$th of what it is at the earth's surface. Newton proved that it is so, by showing that the moon falls towards the earth in a given time, because in its curve it is bent out of the straight line along which it would move were there no attraction of the earth, exactly as far as it would be drawn were it a stone acted on by the earth at that distance. Thus Newton proved that gravitation extends to the moon. Between its own original movement through space under what is called CEN-

TRIFUGAL FORCE, and the attraction of the earth called CENTRIPETAL FORCE, the moon moves in an ellipse round the earth.

The same force, therefore, which drags a stone to the earth, whirls the moon round the earth, and the other satellites round their planets, as well as the planets round the sun. The statement of the mode in which this force acts is called a Law of Nature, because it governs the movements of all bodies in nature. It is a force which acts everywhere without fail; and astronomers calculate from it with such certainty that they tell for years beforehand the place which each planet should occupy in its course. Should the planet fail in its appointed time, or deviate from its appointed course, then the astronomer is certain that the law does not fail, but that somewhere in space there exists an unknown attracting body which causes the unpunctuality. It was a slight unpunctuality of Uranus that thus led to the discovery of the planet Neptune. Two astronomers, Leverrier in France and Adams in England, declared beforehand where the disturbing body should be looked for, and Galle in Germany found it where they had, each independently of the other, said it should be.

Perturbations.

The force of attraction leads to disturbances, or as they are called PERTURBATIONS, of the movements of the earth and moon, because of the greater attraction of the sun and moon on the greater mass of the earth at its equator; and also because of the differences of the attractive force of the sun and the earth upon the moon in different parts of its orbit. Owing to these disturbances the three great circles in the heavens, namely, the ecliptic, the equinoctial, and the moon's orbit, do not always cut each other in the same points or nodes. The moon in her monthly course from west to east, is drawn by the force of the sun towards the line in which the sun always is, namely the ecliptic; she therefore comes upon it at each revolution before she has completed a circle among the stars; and crosses it at a point short of her last crossing point, or onde, by about 19°. Thus in nearly 19 years, since $19^\circ \times 19 = 361^\circ$, the nodes of the moon's orbit make a revolution round the celestial sphere.

Precession of the Equinoxes.

In a similar way the greater force of the sun upon the extra mass of the earth about the equator, draws the particles of this mass successively round towards the sun in the ecliptic. Each year, therefore, the point at which the sun in its path crosses the equinoctial is advanced 50″ from the point among the stars crossed by it the year before, bringing the equinox 20¼ minutes before its time, as it were. This is called the PRECESSION of the equinoxes. Because of it the nodes of the ecliptic and equinoctial describe a circle round the ecliptic in about 25,900 years $(\frac{360 \times 60 \times 60}{50})$.

Change of the Equinoctial Points.

The equinoctial points thus change their places among the stars. Though more than 2000 years ago the spring equinoctial point was in the constellation Aries, it is not so now; but still the node—or crossing point for the time—of the ecliptic and equinoctial is called the point Aries.

Since the equator of the earth is thus made to swing round the ecliptic, it is clear that the poles of the earth must swing too; and they do so round points of the heavens which bear the same central position for the ecliptic that they themselves do for the equator, and which are called the poles of the ecliptic. They therefore in 25,900 years describe a circle round the poles of the ecliptic, in either hemisphere. In consequence of this movement the same star cannot always be above the poles of the earth; indeed every star near the circle of 23½° round the pole of the ecliptic will be so placed at one time or other. The swaying of a top as it spins, gives an idea of the movement of the earth as it slowly sways round, dragged by the stronger attraction of the sun at the equatorial parts than at the other parts of its globe.

Nutation of the Axis.

The moon, too, exerts an attractive force on the parts at the equator, and as its nodes go round the ecliptic in 19 years, the earth's axis under this force is moved slightly, and its extremities tend to describe a small ellipse round the poles of the ecliptic. The tendency thus caused, of the poles of the earth to describe a small ellipse every 19 years modifies the circle which would be described by the poles as a result of precession alone, and converts it into a waving curve—a path such as a tipsy man tends to move along, in walking round a race-course. To this waving or tremulous motion is given the name of NUTATION, or nodding of the axis.

Changing Obliquity of Ecliptic.

The planets, too, by their attraction tend to bring the equator and the ecliptic to the same plane or level, and thus to reduce what is called the OBLIQUITY OF THE ECLIPTIC. That obliquity is about 23½° now; astronomers calculate that it will by and by lessen to 22°; and afterwards by slow changes in the positions of the planets as regards the earth, it will again increase.

Anomalistic Year. From similar causes the ellipse of the earth's orbit revolves in 110,000 years in the same direction as that in which the earth moves, so that the places of perihelion and aphelion, or of nearest and greatest distance from the sun, change in relation to the seasons. The interval from one perihelion to the next is called the ANOMALISTIC YEAR. About 3,600 years before the date of the creation the earth was nearest the sun in the summer of the northern hemisphere, the reverse being the case now. The summer heat and winter cold must then have been greater by far than they are at present.

Change of Excentricity of Orbit. The excentricity of the earth's orbit changes also in long periods of time, and therefore the sun, within such periods, must be much nearer the earth than it is at its nearest now, and much farther from it than it is at its farthest now. Suppose that at a period of greatest excentricity the earth's north pole be turned away from the sun at the time when the earth is in aphelion, then would possibly occur one of those periods called by the geologists glacial epochs, when all Europe would be covered by snow and ice, as only the polar regions are now. The winters would then be longer than the summers, for the earth takes a week longer to perform the aphelion half than the perihelion half of its orbit; and the short summers would not be long enough to melt the yearly accumulating mass of ice and snow. It has recently been calculated that such a period of high excentricity extended from about 980.000 to 720,000 years ago; and another began about 240,000 and lasted till 80,000 years ago. This last would therefore be the last glacial epoch of the geologists.

EXERCISES.

What wider law did Sir Isaac Newton induce from Kepler's laws? State the rates at which bodies fall in a few seconds near the surface of the earth. By what rule may one calculate the actual distance which a body falls near the earth's surface in a given time? To what heavenly body did Newton prove that the law of the velocity of bodies falling near the earth's surface applied? What are perturbations? In what time do the nodes of the moon's orbit revolve round the ecliptic? What effect has this revolution upon the succession of eclipses? What is precession of the equinoxes? What causes it? What is nutation of the earth's axis? and what is its cause?

XII.

MAPS.

Projections. Since the earth is round, it is clear that the only correct representation which can be given of the lands and seas on it in their proper latitudes, longitudes, and shape must be given on the surface of a globe. But globes are inconvenient and expensive, therefore maps have been brought into use. In these the rounded surface of the earth is represented on flat paper, and hence there must be distortion of the objects represented. Different methods have been adopted to reduce this distortion, or to modify it; and any plan by which the spherical surface is sought to be represented on a plane, is called a PROJECTION.

There are five different projections: the *Stereographic*, *Orthographic*, *Globular or Equidistant*, *Conical*, and *Mercator's*.

Stereographic.

The Stereographic projection of a Map of the World in two hemispheres, shows each hemisphere as an eye at the antipodes of the central point of that hemisphere would see it were the globe hollow and transparent, and

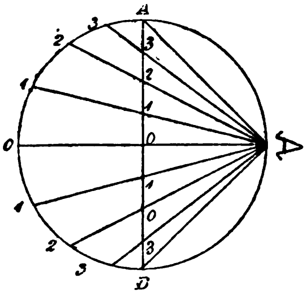

Fig. 14.
Stereographic Projection.
The straight line AB is a section of the plane of projection. The equal spaces marked by the figures between A and B on the straight line represent unequal spaces marked along the curve between A and B.

a plane of glass or transparent paper stretched through its centre across a large circle. On this transparent plane the coast line, capes, &c., of the hemisphere opposite to the eye may be considered to be drawn much in the same way as a landscape outside may be outlined on one of the panes of a window; or the rays passing through the central plane to the eye may be considered to photograph the objects on that plane as they pass through it. In a map of the world on this projection parts near the centre are too small compared with the parts near the circumference.

Orthographic. The Orthographic projection is a representation on a similar plane, but the eye is considered to be at an infinite distance from the globe, and the rays or lines pass through the central plane perpendicular to it, and, therefore, parallel to each other. In a map on this projection parts near the circumference are too small compared with the parts near the centre.

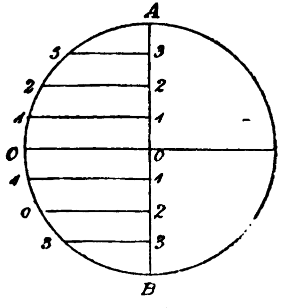

Fig. 15.

Orthographic Projection.

AB, the plane of projection. The equal spaces between A and B on the plane represent the unequal spaces marked by the figures between A and B along the curve.

Globular. The Globular or Equidistant projection is a representation on a similar plane, but the eye is considered to be at the distance of half the chord of a quadrant from the surface of the earth opposite to that represented. Lines from equally distant parts of the circumference to a point at this distance cut the plane of projection at points equally distant, and thus equal spaces on the earth are represented by equal spaces in this projection. The equidistant is usually chosen for maps of the World in hemispheres.

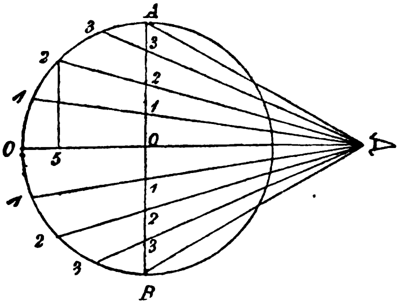

Fig. 16.

Globular Projection.

The equal spaces on the plane of projection AB represent the equal spaces on the curve. The line from 2 to 5 is half the chord of a quadrant.

In each of these three projections the equator and the central meridian of the map are projected into straight lines. In the orthographic the parallels are also straight lines, and the meridians are ellipses. In the stereographic the meridians and the parallels are parts of circles. The equidistant projection maintains, indeed, the areas of the countries in just proportion, but distorts their shape considerably.

Any great circle may serve as the plane for such projections. If the Equator be chosen, we have a Map of the World divided into Northern and Southern hemispheres. The circle whose circumference is everywhere 90° from London, would, if chosen as the plane of projection, give us Maps of the World on the horizon of London and of its Antipodes, and divide the World into the hemispheres of greatest land and of greatest water. The plane of the meridian of 20° West of Greenwich is the usual plane of projection for the map of the world when divided into Eastern and Western hemispheres.

Mercator's. In Mercator's projection the Globe is supposed to be enclosed in a cylinder which exactly fits it at the equator, and the surface is supposed to be expanded or stretched out, Northward and Southward, till it touches the inner surface of the cylinder. The outlines of the countries &c., are then, as it were, transferred from the outer surface of the globe to the inner surface of the cylinder at the parts where they touch. The cylinder is afterwards cut, and opened out as one would open out a scroll. The parallels and meridians are here all straight lines, at right angles to each other, and the spaces between the meridians are equal; that is, in this map or projection the degrees of longitude are all of the same length as those on the equator. The farther North and South, therefore, any place is situated, the greater is the exaggeration of its length from East to West; and to preserve something like the shape of Northern and Southern lands, the spaces between the degrees of latitude are exaggerated in the same proportions as those between the degrees of longitude.

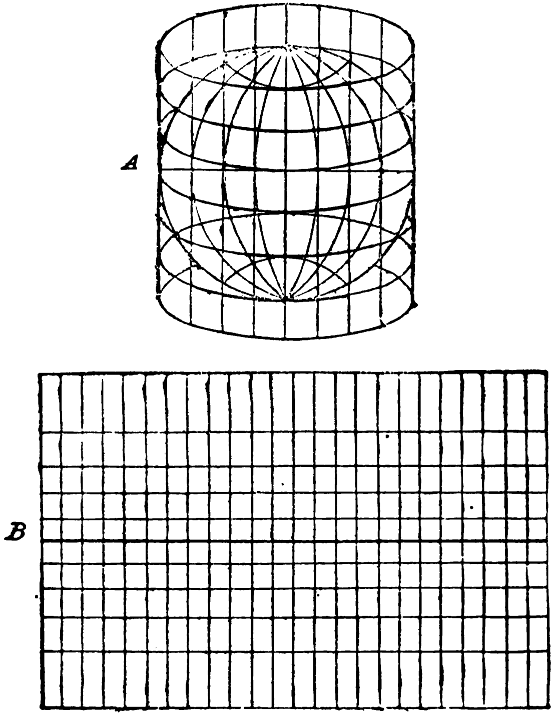

Fig. 17.
Mercator's Projection.
A, globe enclosed in cylinder. B, cylinder opened out.

Its use. This projection forms a Chart rather than a Map; being chiefly of use at sea. A line drawn on it from any one point to another cuts all the meridians at the same angle, and is called a RHUMB LINE. A captain draws on his chart a line from the port at which his vessel is, to the port which he wishes to reach, and observes the angle at which it cuts the meridians. An angle of 45° formed by the line between the two places and the meridians, to the West of his position as marked on the chart, tells him that by holding a course due North-west he would without fail reach the desired port.

Great Circle Sailing.

Along this line, however, would not be his shortest way between the two ports. The shortest possible distance on the surface between any two points upon a sphere is along a great circle of that sphere. The less a circle curves, the nearer any distance on its circumference is to a straight line. For places, therefore, that are on the equator, or for places on the same meridian, the shortest distance between them is along the Equator or along the meridian; but for two places not so situated the course of a great circle is difficult to trace. A set of rules has been drawn up, by attending to which a vessel may be kept on the curve of a great circle between two places; and this is called GREAT CIRCLE SAILING. These rules, however, are so difficult to follow, that it is often better, as it certainly is always easier, to take the longer route between the places, namely, that, which is represented by the straight line joining them in Mercator's Chart.

The Conical Projection.

The projection mostly used for Maps of parts of the world, such as particular countries or districts, is that called the conical projection. In it a cone is supposed to fit round the world at the middle latitude of the country to be represented, exactly as the cylinder is supposed to fit round the equator in Mercator's projection, and the surface of the country is then supposed to be expanded till it touches the inner surface of the cone at a sufficient distance on both sides of the middle latitude. The parts of the sphere to be included in the map are then transferred to the inner surface of the cone, which is unrolled, like Mercator's cylinder, and the Map of the country is thus found on the plane of the developed cone. In such a map the meridians are straight lines converging to the apex of the cone, instead of, as on the sphere, circles converging to the pole. The parallels are arcs of circles described from the apex of the cone as a centre, and by the rules of trigonometry, the distance of the apex of a cone touching all round the sphere at any latitude, that is,

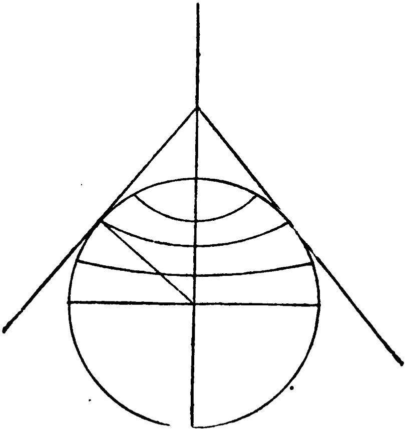

Fig. 18.
Conical Projection.

the centre of the circle from which the parallels must be drawn, is easily found. It is, for each latitude, always the length of a known number of degrees of the sphere.

Projections for Special Maps.

England is best represented by projection on a cone supposed to touch the sphere round the 53rd parallel of North Latitude. In the Map of the British Isles the middle latitude should be the 55th degree. For a map of Europe the 50th would be the best parallel for the centre, since along it lie the most important parts of that division of the globe; and the exaggerations of the conical surface would be thrown upon the unimportant countries of the North, and upon the Mediterranean and Black Seas in the South. The central meridian of the map of Europe is the line of 20° east longitude.

Delisle's Method.

The Map of Asia is usually drawn on a modification of the conical

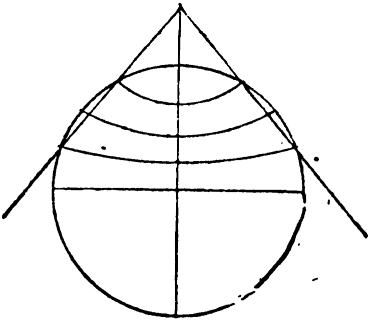

Fig. 19.
Delisle's Conical Projection.

projection, called Delisle's Method, by which the cone, instead of touching the globe round one parallel, cuts it at two, entering at one and leaving at the other; and therefore the inner surface of the cone corresponds exactly with the outer surface of the globe at both. In Asia the cone intersects at the 25th and 60th parallels of North latitude, and the central meridian is 85° East.

Flamstead's Projection.

Sometimes Asia is drawn on a projection called Flamstead's method. In this the parallels are straight lines, or arcs of concentric circles. The meridians are drawn through the parallels, not as straight lines converging to the apex of a cone, but as curves cutting each of the parallels at distances proportionate to the decrease in the length of the degrees of longitude on the successive parallels.

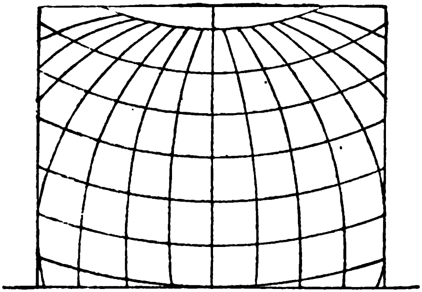

Fig. 20.
Flamstead's Projection.

Since Africa extends on both sides of the Equator, the conical method is inapplicable, and Flamstead's method is usually adopted. The cenral meridian is that of 20° east longitude, and is a straight line; while the parallels are also strait lines which cross it at right angles and at equal distances for every 10 or 15 degrees of latitude. The other meridians are made to cut the parallels in points found according to the proportionate length of degrees of longitude on each parallel. In the Map of South America the same method of projection is used, the central meridian being that of 60° West longitude. Flamstead's method with the parallels as concentric curves is used commonly for the Map of North America,—the central meridian being that of 100° West longitude.

Maps of Australia and of the islands of the Pacific are commonly drawn on Mercator's projection.

Map Drawing in Relief.

The different projections form the framework within which the different parts of the coast line or boundary of a country, its river lines and mountain chains, may be drawn in the latitudes and longitudes reported by surveyors or explorers. The coast line of each continent or island shews the shape which that island or continent has at the present sea level. But the interior of a country is generally higher than that level, otherwise the waters of the ocean would flow over it; and the different parts of the interior vary in height from low marshy ground and plains scarcely high enough to keep out the waters, to elevated plateaux and the summits of the highest mountains. Different modes have been adopted of expressing in maps these variations of height—the relief, as it has been called, of the earth's surface. The objects to be attained by the representation of relief, in a map are either: (1) Such mathematical exactness as is needful for the railway surveyor or the military engineer; or (2) Such faithfulness of representation to the eye, and correctness of the mental picture conveyed by the map as is suitable for educational purposes.

Contour Line Maps.

Contour line maps aim at scientific accuracy in the representation of heights and slopes. To understand their method let us suppose that the surface of the ocean were raised 500 feet higher than its present level. The low plains of all islands and continents would be submerged, the area of the land diminished, and the coast line changed. The new coast line might be represented on a map of the lands as at present existing, by curved lines drawn within the former coast line. In a similar manner the coast lines that would be formed were the sea level to rise 1,000, 1,500, 2,000, &c. feet might be drawn. Such lines—lines, namely, joining all points of a country that are of the same height—are called CONTOUR LINFS, and a map with a sufficient number of such lines correctly drawn would represent faithfully the relief of a country. Where the land rises suddenly the contour lines would be close together; where wide level plains exist, the lines would be far apart. Thus the mountain regions in such a map would be dark, and the valleys or plains light, while the spaces between the contour lines might be shaded so as to give the effect of the different slopes. Contour line maps to be useful must be drawn on an immense scale, and unless the lines be very numerous they fail in representing pictorially the inequalites of a country. They are chiefly of use for draining, roadmaking, fortification, and the like, and have been adopted in the construction of the Maps of the Ordnance Survey. The invention is of French origin.

Lehmann Maps. Attempts have been made to express relief of surface by various modes of shading, without contour lines. In the Saxon or Lehmann system of map drawing a level plain is left white, while a slope of 45° is wholly black. Intermediate slopes are expressed by different grades of shading for each difference of 5°. On a slope of 40° the black is to the white as 8 to 1; on a slope of 35°, as 7 to 2; on a slope of 30°, as 6 to 3: and so on through the nine stages of 5°, from all black at 45° to all white at 0° of slope. Relief in this way may be as truly expressed as by contour lines.

Photo-Lithograph Maps. But these methods of shewing the physical features of a country are far too costly for ordinary educational purposes, as well as wanting in pictorial effect. Amongst the better class of maps adapted for school use, the German wall maps of Sydow may be mentioned. But the most effective of all modes of representing to the eye the irregularities of surface, and therefore the best for scholastic purposes, is that employed in the series of photo-lithograph maps issued by the publisher of the present work. In this series the maps are photo-lithographed from models in relief of the countries represented. The level country is shown by green tints, the deepest green showing the lowest lying land, while the high lands are done in faint shading, and the mountains rise in strong light and shade according to their height. Thus the map becomes as nearly as possible like a coloured photograph of the surface of the country, and from it the eye catches readily the leading physical features of the district mapped.

While possessing these advantages in the representation of relief, the maps of this series are not more costly than ordinary maps of the same dimensions.

EXERCISES.

Why are maps more useful than globes? What is a projection? Name five different kinds of projections. What is the nature and chief defect of the stereographic projection? Of the orthographic? Of the globular or equidistant? What circle divides the northern and southern hemispheres? The eastern and western? The hemispheres of land and water? What is the nature of Mercator's projection? In what respect does it fail to represent different portions of the earth's surface correctly? What is its use? What is the line of least distance between two points on the surface of a sphere? What is great circle sailing? What is a rhumb line? Why is it easier to sail along a rhumb line than along a great circle of the globe? What is the nature of the conical projection? On what projection are maps of England and Europe usually drawn? What is Delisle's method of conical projection? What is Flamstead's method of projection? Of what nature is the projection on which maps of Africa and South America are usually drawn? On what projections are the maps of North America, and those of Australasia commonly drawn? What is meant in Geography by 'relief?' What are Contour lines? Explain the Saxon method of Map shading. What are photolithograph Maps? For what different purposes are contour line Maps and Photolithograph Maps adapted?

ETYMOLOGY OF TERMS.

Aberration ...	*ab*, from, and *errare* to wander. Lat.
Aerolite ...	*ἀήρ*, the air, and *λίθος* a stone. Gr.
Altitude ...	*altitudo*, height. Lat.
Angle	*angulus*, a corner. Lat.
Annular ...	*annulus*, a ring. Lat.
Aphelion ...	*ἀπό*, from, and *ἥλιος*, the sun. Gr.
Apogee... ...	*ἀπό*, from, and *γή*, the earth. Gr.
Azimuth ...	an approach. Arabic.
Calendar ...	*calendae*, the first day in each month. Lat.
Cardinal ...	*cardo*, a hinge, *cardinalis*, chief. Lat.
Comet	*κομήτης*, hairy. Gr.
Culmination	*culmen*, the top, summit. Lat.
Eclipse... ...	*ἔκλειψις*, a disappearance. Gr. Hence
Ecliptic ...	the line in which eclipses occur.
Equinox ...	*aequus*, equal, and *nox*, night. Lat.
Gravitation ...	*gravis*, heavy. Lat.
Gyroscope ...	*γῦρος*, a curve, and *σκοπέω*, I see. Gr.
Hemisphere	*ἡμι*, half, and *σφαῖρα*, a sphere. Gr.
Horizon ...	*ὁρίζων*, a boundary. Gr.
Latitude ...	*latitudo*, breadth. Lat.
Longitude ...	*longitudo*, length. Lat.
Meridian ...	*meridies*, midway. Lat.
Nodes	*nodus*, a knot. Lat.
Nutation ...	*nutatio*, a nodding. Lat.
Orbit	*orbis*, a circle. Lat.
Orthographic	*ὀρθὸς*, straight, and *γράφειν*, to draw. Gr.
Paralax ...	*παραλλαξις*, a change. Gr.
Penumbra ...	*pene*, almost, and *umbra*, a shadow. Lat.
Perigee ...	*περί*, near, and *γῆ*, the earth. Gr.
Perihelion ...	*περί*, near, and *ἥλιος*, the sun. Gr.
Period	*περί*, round, and *ὁδός*, a path. Gr.
Perturbation	*perturbare*, to interfere with. Lat.
Phases	*φάσις*, an appearance. Gr.
Planet	*πλανήτης*, a wanderer. Gr.
Pole	*πολέω*, I turn. Gr.

Precession	*praecedere.* to go before. Lat.
Refraction	*re,* back, and *frangere,* to bend. Lat.
Satellite	*satelles,* a companion. Lat.
Sidereal	*sidus,* a star. Lat.
Solstice	*sol,* the sun, and *stare,* to stand still. Lat.
Syzigies	*συζυγία,* a yoking together in one line. Gr.
Stereographic	*στερεὸς* solid, and *γράφειν,* to draw. Gr.
Telescope	*τῆλε,* afar, and *σκοπέω,* I see. Gr.
Transit	*trans,* across, and *ire,* to go. Lat.
Tropic	*τρέπειν,* to turn. Gr.
Vertical	*vertex,* the top. Lat.

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